REPORT #
RRTAC 90-7

Reclamation of Disturbed Alpine Lands:

A Literature Review

Heritage Fund

Alberta
LAND CONSERVATION AND
RECLAMATION COUNCIL
Reclamation Research
Technical Advisory Committee

Alberta's Reclamation Research Program

Regulating surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council. The Council executive consists of a Chairman from Alberta Environment and two Deputy Chairmen from Alberta Forestry, Lands and Wildlife. The Council oversees a reclamation research program, established in 1978, to identify the most efficient methods for achieving acceptable reclamation in the province. Funding for the research program is provided by Alberta's Heritage Savings Trust Fund, Land Reclamation Program.

To assist with the development and administration of the research program, the Council appointed the inter-departmental Reclamation Research Technical Advisory Committee (RRTAC). The Committee consists of eight members representing the Alberta Departments of Agriculture, Energy, Forestry, Lands and Wildlife, and Environment, and the Alberta Research Council. The Committee updates research priorities, reviews research proposals, organizes workshops, and otherwise acts as the coordinating body for reclamation research in Alberta.

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REPORT #
RRTAC 90-7

RECLAMATION OF DISTURBED ALPINE LANDS:

A LITERATURE REVIEW

Prepared by

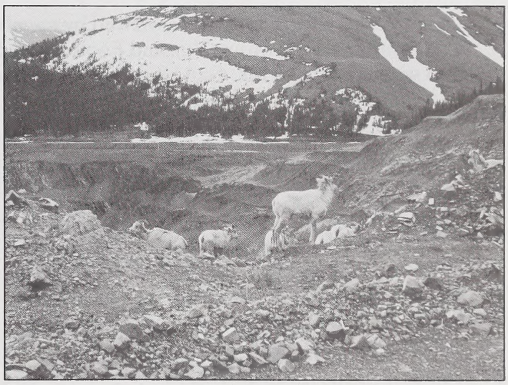
Hardy BBT Limited

Prepared for

The Mountains and Foothills Reclamation Research Program
ALBERTA LAND CONSERVATION AND RECLAMATION COUNCIL
(Reclamation Research Technical Advisory Committee)

1990

Mountains and Foothills Reclamation Research Program



DISCLAIMER

This report is intended to provide government and industry staff with up-to-date technical information to assist in the preparation and review of Development and Reclamation Approvals, and development of guidelines and operating procedures. This report is also available to the public so that interested individuals similarly have access to the most current information on land reclamation topics.

The opinions, findings, conclusions, and recommendations expressed in this report are those of the author(s) and do not necessarily reflect the views of government or industry. Mention of trade names or commercial products does not constitute endorsement, or recommendation for use, by government or industry.

Some editing of the text was done following receipt of the final document. While the changes were discussed with the authors of the report, they did not have an opportunity to see the final copy.

REVIEWS

This report has been reviewed by members of the Reclamation Research Technical Advisory Committee and the Mountains and Foothills Reclamation Research Program Committee. RRTAC also wishes to thank Ms. Gail Harrison, Canadian Parks Service for her extensive review comments.

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ABSTRACT

This study was undertaken to collect and review information from North American sources on measures needed to reclaim alpine disturbances. The alpine environment was defined as those physical and biological conditions occurring on mountains above the climatic upper limits of tree growth.

On a given site, the distribution of alpine plants and soils is strongly affected by topography through its influence on solar radiation, soil moisture, soil and air temperatures and both the blasting and protecting aspects of snow. These interact to produce an alpine moisture gradient and a length of growing season gradient caused by differential snowmelt. Knowledge of these relationships can provide information on sensitivities of plant communities to disturbance, and a framework for reclamation planning.

In Alberta, recent disturbances to the alpine are primarily associated with the development and use of ski facilities and hiking trails. Wildlife range, watershed protection, and recreation are the main land uses. The potential for changing post-disturbance land uses is limited in the alpine because of the harsh climate and limited choice of plant species suitable for revegetation.

Research on alpine reclamation in North America has primarily concentrated on identification and selection of plant materials which can withstand the harsh conditions. Research on methods to enhance the establishment of plant cover including such factors as surface preparation; use of mulches and fertilization has been sparse and has often yielded contradictory results.

The addition of topsoil to disturbed spoils has been shown to greatly enhance plant establishment and growth. Several seed mixtures will likely be required to successfully revegetate large disturbance areas. It is recommended that mixtures of agronomic and native species be used. Each mixture should be matched to the microsite to which the component plant species are best adapted.

Transplanting may be the best revegetation technique on particularly harsh sites where conventional seeding methods are not practical.

EXECUTIVE SUMMARY

This study was undertaken to collect and review information from North American sources on measures needed to reclaim alpine disturbances. The alpine environment was defined as those physical and biological conditions occurring on mountains above the climatic upper limits of tree species.

Alpine areas (outside of National Parks) in Alberta are designated under the Policy for Resource Management of the Eastern Slopes as prime protection zones. Alpine lands are also classified under the Coal Development Policy as category one in which no exploration or commercial development is permitted. Development of alpine lands may be subject to provisions of the Land Surface Conservation and Reclamation Act, Water Resources Act, Clean Water Act and the Public Lands Act.

Climate of the alpine environment is characterized by cool growing season temperatures, persistent strong winds, high solar radiation loads, a short growing season with potential for frost at any time, and highly variable snow distribution. The climate is harsh and alpine environments represent the near ecological limits of many plant species.

On a given site, the distribution of alpine plants and soils is strongly affected by topography through its influence on solar radiation, soil moisture, soil and air temperatures and both the blasting and protecting aspects of snow. These interact to produce an alpine moisture gradient and a length of growing season gradient caused by differential snow melt. Knowledge of these relationships can provide information on sensitivities of plant communities to disturbance, and a framework for reclamation planning.

In Alberta, recent disturbances to the alpine are primarily associated with development and use of ski facilities and hiking trails. These uses are primarily concentrated in Banff and Jasper National Parks. Minor areas are disturbed through the use of ATV's and road and powerline construction. Downhill skiing and snow grooming can result in significant changes in snow distribution, layering and density. This may lead to changes in plant communities, nutrient cycling and soil erosion. The susceptibility of various plant species to trampling is influenced by season of hiking use, duration of use, and intensity of use. Wet areas and late-lying snowbeds are most susceptible to damage.

Wildlife range, watershed protection, and recreation are the main land-uses at present in the alpine in Alberta. The potential for changing post-disturbance land uses is limited in the alpine because of the harsh climatic conditions and the limited choice of species suitable for revegetation. The primary short-term reclamation objective is to provide a stabilizing plant cover to prevent erosion. Over the long-term, the reclamation objective is to establish a self-sustaining plant community that permits recolonization by native plants of the local area.

Reclamation planning in the alpine requires a knowledge of snow distribution and snow melt patterns. Slopes should be contoured to promote even snow distribution to facilitate ease of revegetation. Ridges tend to be dry in summer and subject to wind erosion, while depressions have excessive snow accumulation and a resultant short growing season.

The addition of topsoil to disturbed spoils has been shown to greatly enhance plant establishment and growth, and to reduce the need for maintenance fertilization. At present, there is insufficient information to present detailed criteria for soil salvage and replacement. Peat moss, manure and straw have all been used successfully as organic amendments at rates of 2000 to 4000 kilograms per hectare.

Surface mulches could possibly enhance seedling establishment by reducing moisture loss, wind erosion and the formation of needle-ice. However, field trials with mulches in the alpine have yielded inconclusive results.

Several seed mixtures will likely be required to successfully revegetate a large disturbance area. It is recommended that mixtures of agronomic and native species be used. Each mixture should be matched to the microsite to which the component plant species are best adapted. Recommended seeding rates range from 200 to 500 total viable seeds per m^2. On harsh sites, seeding rates should be close to the higher rate, whereas more favourable sites should be seeded close to the lower rate. In general, seeding should be done in the fall to allow for cold stratification and germination under optimum conditions during spring snowmelt.

In general, fertilizer applications are considered essential for successful establishment of plant cover on alpine disturbances. Continued high application rates of fertilizer may favour the high growth rate-adapted

and high nutrient-adapted species, and result in reduced rates of invasion by native species. One method that was found to be effective was to apply fertilizer in both the first year, and early in the second or third growing season, and then wait until the stand becomes nutrient deficient before applying another application.

On particularly harsh sites where conventional seeding methods are not practical, transplanting may be the best revegetation technique available. Survival rates are generally high but plants must be transplanted to the appropriate microsite. Tussocks of some alpine grasses can be successfully subdivided into single tillers which can be transplanted. Transplanting success tends to be lower in the fellfield sites and higher in the snowbed and wet meadow sites. Wide ranging species tend to be the best transplanters.

Transplanting alpine vegetation sod is also a successful method for revegetating small areas. Microsites must be matched even when moving sod short distances.

A list of research needs which have been noted by various researchers in the literature was given. This included research on impacts of various types of disturbances in the alpine, plant adaptations, species selection, revegetation, fertilization, soil and surface amendments, and equipment.

1. INTRODUCTION

Alpine ecosystems are being subjected to ever-increasing development activities and use. This has resulted in increased impacts on these sensitive ecosystems.

Alpine areas are characterized by a severe physical environment, with strong winds, long cold winters and a short, cool growing season. The low temperatures produce slow plant establishment, poor nutrient uptake and result in low annual biomass production. These severe conditions in the alpine present special challenges for reclamation of disturbed areas.

Successful reclamation of disturbed alpine areas requires a detailed knowledge and understanding of the environment. Research into the reclamation of disturbed alpine lands is still very much in its infancy with most research in North America concentrated in Montana, Utah, and Colorado. Most high altitude reclamation research in Alberta and British Columbia has been undertaken at subalpine elevations where environmental conditions are much less adverse.

1.1 OBJECTIVES

This study has been undertaken to collect and review information from North American sources on measures needed to reclaim alpine disturbances.

The specific objectives of this study are as follows:

1. To review North American literature on reclamation of alpine disturbances;
2. To contact reclamation specialists in Alberta, British Columbia, and the United States and obtain information on reclamation of alpine disturbances;
3. To describe the types of disturbances to alpine lands in Alberta;
4. To describe measures needed to reclaim disturbances to alpine lands in Alberta; and
5. To identify research needs for reclamation of alpine disturbances in Alberta.

1.2 DEFINITION OF TERMS

For the purposes of this report, the alpine environment is defined as those physical and biological conditions occurring on mountains above the regional climatic upper limits of tree species. However, it is important to note that these limits are seldom sharp; the ecotone between alpine environments and subalpine forest is often broad (Billings 1974b). In some cases, timberlines exist at much higher elevations than the lowest patches of alpine vegetation.

A variety of terms are used to describe the process of repairing disturbed lands. These include reclamation, rehabilitation and restoration. Each of these terms has been variously defined (Brown 1984; DePuit 1986; Goodman and Bray 1975). In this report the term 'reclamation' is used in the broadest sense to mean restoring the land's original capability.

Specifically, the concept of reclamation includes methods for:

1. Designing a disturbance in a manner that minimizes hazardous conditions and protects the surface against wind or water erosion;
2. Revegetating and managing the land to ensure re-establishment of land capability equivalent to that of the original undisturbed land;
3. Re-establishing surface water resources; and
4. Re-establishing landscape character and scenic values.

For the purposes of this report the term 'restoration' is defined as re-establishment of the original land-use. The definitions of other terms used in this report are contained in a glossary at the back of the report.

1.3 STRUCTURE OF REPORT

This report is divided into six main sections. Section 2. provides a brief description of both provincial and federal regulations that affect developments in the alpine. An overview of the Alpine Ecoregion in Alberta is provided in Section 3. Section 4. provides a description of the types of disturbances to the alpine in Alberta and the associated impacts on alpine ecosystems. A review of the literature relating to various aspects of reclamation in the alpine is presented in Section 5. This includes information on reclamation goals, site preparation, surface preparation, and

revegetation. Section 6. provides a summary of information relevant to the reclamation of disturbances to the alpine in Alberta. It includes information on site and surface preparation, selection of appropriate plant species, establishment methods, and maintenance and monitoring requirements. It also includes a description of information requirements for reclamation planning and a detailed list of research needs to address information gaps identified in the literature.

2. REGULATIONS

This section provides a brief description of the various acts and regulations that may affect development of alpine lands in Alberta. Neither the list, nor the treatment of the various acts, regulations or policies is meant to be complete; the reader is directed to the appropriate government agencies for more detailed information regarding development in the alpine.

Both the Land Surface Conservation and Reclamation Act and the Clean Water Act will be replaced in 1991 by the Alberta Environmental Protection and Enhancement Act.

2.1 LAND SURFACE CONSERVATION AND RECLAMATION ACT

General development and reclamation criteria for mining under the Land Surface Conservation and Reclamation Act include provisions for water management, soil conservation, revegetation and interim land management, infrastructure concerns, and aesthetics and safety (Government of the Province of Alberta 1984a).

Water management development plans must include consideration of water system integrity for off-site areas, implementation of effective erosion control procedures, and establishment of adequate drainage systems. During reclamation, surface drainage patterns must be integrated with off-site drainage patterns, and establishment of water bodies or watercourses on reclaimed landscapes must be in accordance with approved design.

Materials handling must provide for salvage of topsoil and suitable subsoils, and maintenance of these salvage piles on stable, protected foundations. During contouring, unsuitable materials must be adequately disposed of, and all excavations must be filled and graded to contours compatible with the final landscape. Retained pit walls must be geotechnically stable and properly angled to be compatible with the post-development land capability. Discard dumps must not exceed 27 degree slopes.

Wildlands, identified under the Act, are those areas where intensive and sustained management typical of agriculture and commercial forestry are absent. Alpine lands would correspond to wildlands under the Act. Soil replacement on these sites must be of sufficient depth and suitability to sustain a maintenance-free vegetative cover that meets the intended post-development land capability.

Suitable species must be seeded as soon as possible following contouring on all disturbed sites. The land must be maintained and managed until a Reclamation Certificate is issued.

Access roads and haul roads must be reclaimed at the time of project abandonment, and reclaimed land must be left free of unnecessary structures, materials and equipment. All hazards, hazardous substances, garbage, debris, or other waste materials must be eliminated.

2.2 WATER RESOURCES ACT

The Water Resources Act prohibits interference with the present or future development, conservation or management of water by establishing devices near water bodies or by disturbing materials that form the bed, shore or banks of water bodies (Government of the Province of Alberta 1986).

2.3 CLEAN WATER ACT

The Clean Water Act prohibits the contamination of, or changing water quality of, any watercourse without the written permission of the Director of Standards and Approvals or the Director of Pollution Control (Government of the Province of Alberta 1988).

2.4 PUBLIC LANDS ACT

The crown holds a large part of alpine lands. Development activities in the alpine are therefore, subject to regulations made under the Public Lands Act. A wide range of land-uses are covered under this Act: commercial trail riding and other recreation uses, easements for electric transmission lines, grazing leases, and mineral exploration. The Public Lands Surface Reclamation Regulations apply to lands affected by well drilling, pipeline construction, and operation or abandonment of a mine or quarry operation except where the Land Surface Conservation and Reclamation Act applies (Government of the Province of Alberta 1987).

2.5 COAL DEVELOPMENT POLICY

Alpine lands are classified under the Coal Development Policy as Category One (Alberta Energy and Natural Resources 1976). These are lands in which no exploration or commercial development will be permitted. These areas

are classified in this manner because they are associated with high environmental sensitivity, and because reclamation of these lands cannot be assured with existing technology, and for watershed protection. Other areas with a similar classification include National and Provincial Parks, wilderness areas, natural areas, restricted development study areas, watershed research study areas, designated recreation areas, heritage sites, and wildlife sanctuaries.

2.6 EASTERN SLOPES POLICY

Alpine areas in Alberta are designated under the Policy for Resource Management of the Eastern Slopes as prime protection zones (Government of the Province of Alberta 1984b). Criteria used to identify these areas include elevation, terrain sensitivity, and aesthetic features. The lower boundary of the zone exists at 1676 m A.S.L. north of Calgary, and 1981 m A.S.L. south of Calgary. Watershed protection is of paramount concern in this zone, along with the preservation of rare or fragile biologic communities and natural landscapes. Critical wildlife ranges, especially for bighorn sheep and mountain goats, are included in the prime protection zone.

Land-use in this zone is characteristically "back-country" recreation activities such as hiking, fishing, and hunting. Scientific study and research projects not requiring land dispositions are allowed under normal conditions of environmental protection. Serviced camping facilities are not permitted.

Commercial development for transportation and utility systems will not normally be permitted. However, development of commercial ski areas may be permitted. In the latter case, only ski lifts and associated facilities will be permitted in the prime protection zone. Accessory facilities (lodges, stores, etc.) must be constructed in other zones.

Major roads and utility corridors may be constructed in the prime protection zone. Stringent environmental conditions and resource management controls will be applied.

Land-use activities presently not permitted in this zone include mineral exploration and development, petroleum and natural gas exploration and development, commercial timber operations, domestic grazing and cultivation,

industrial development, residential development, and off-highway vehicle activities.

2.7 INTEGRATED RESOURCE PLANS

Integrated Resource Plans (IRP's) are detailed policy and planning documents, the development of which is coordinated by the Resource Planning Branch of the Public Lands Division (Government of the Province of Alberta 1984b). IRP's are similar to the Eastern Slopes Policy. However, they provide scope for more detailed planning; the scale used for IRP's is 1:100 000 while that for the Eastern Slopes Policy is 1:500 000. The development of IRP's involves both interdepartmental participation, as well as public input.

2.8 NATIONAL PARKS POLICY

The National Parks have adopted a zoning system by which land and water areas of a national park are classified according to their need for protection and their capability to accommodate visitors (Parks Canada 1980). It provides a guide to activities of both visitors and managers, and assists in allocating the resource for use or preservation. These zones include: Special Preservation (Zone 1), Wilderness (Zone 2), Natural Environmental (Zone 3), Outdoor Recreation (Zone 4), and Park Services (Zone 5). Alpine areas are frequently zoned as wilderness areas and occasionally as special preservation areas. For both these zones visitor access is restricted to non-motorized transport, with restrictions placed on numbers of users. Construction of facilities is not permitted.

The Parks Policy (Parks Canada 1980) also provides some guidelines relevant to alpine reclamation. "A species of plant or animal which has been native to, but which is no longer present in the park area, may be reintroduced:

1. If the effect on other plants and animals is acceptable; and,
2. If such action is compatible with park objectives; and,

3. If such action does not pose serious problems for neighbouring land-users."

"Non-native species of plants and animals will not be introduced into a national park and, where they exist, efforts will be made to remove them."

3. SETTING

The Alpine Ecoregion occurs above climatic forest-line in the Rocky Mountains (Strong and Leggat 1981). It is situated where the contiguous forest ends and isolated islands of trees begin (Ogilvie 1976). Isolated patches of krumholz and dwarfed trees characteristic of the subalpine can be considered part of alpine ecosystems (Brown et al. 1978b). The elevation of the tree-line in Alberta ranges from 2135 m A.S.L. in the south to 1980 m A.S.L. in the north (Table 1).

Table 1. Tree-line elevations in Alberta, British Columbia, and the United States

	Alberta		British Columbia			United States		
	S	N	SE	SW	N	SW	Montana	New England
Elevation (m A.S.L.)	2135	1980	2290	1680	900	3500	2000	1500

Adapted from original tables in Brown et al. (1978b), Strong and Leggat (1981), Thirgood (1978).

The Alpine Ecoregion is discontinuous and is estimated to comprise approximately 18 506 km^2 or 2.8% of the area of Alberta. The following discussion describes environmental factors affecting reclamation of disturbed alpine lands.

3.1 CLIMATE

The dominant climatic factor which characterizes the Alpine Ecoregion is low temperatures. However, other factors which are also important, particularly with regard to reclamation are: wind, solar radiation, precipitation, and length of the growing season. A summary of climatic data for the Alpine Ecoregion in Alberta is given in Table 2. The major climatic factors are described below, along with a brief discussion of their influence on reclamation in the Alpine Ecoregion. It should be noted that the alpine is composed of surfaces with all aspects and a wide range of slope angles. During summer, the climates of steep south-facing slopes differ markedly from

Table 2. Climate data summary for Alberta's alpine ecoregion. [a]

Mean Annual Temperature °C			Total Precipitation (mm)			Oct. to Apr. Precipitation (mm)			May to September									
									Mean Temp. °C			Number Days 0°C or less			Precipitation (mm)			
Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	% of Annual
-4.5[b]	-4.5	-4.5	730	970	570	400	590	240	6.5	7.5	4.0	10	10	10	360	430	270	48

[a] Adapted from the original table in Strong and Leggat (1981).

[b] Data from one climate recording station only.

north-facing slopes. During winter, southwest and northwest-facing slopes may be completely snow-free, whereas east aspects or protected pockets may have snow over several metres deep which may last well into summer, or even year round (Strong and Leggat 1981). Regional climatic data are given here to provide a rough guide to the severe climatic conditions of the Alpine Ecoregion in Alberta.

3.1.1 Temperature

Mean summer temperature has been estimated as 6.5°C for the Alpine Ecoregion in Alberta (Table 2) with a range of 4.0°C to 7.5°C.

The mean July temperatures are 10°C or lower. The occurrence of freezing temperatures in the alpine is spatially variable. Exposed south-facing slopes may have frost-free periods in excess of 25 days, but depressions and protected areas may be limited to frost-free periods of several days in length.

Temperatures may fall below 0°C during the growing season, restricting photosynthesis, and nutrient and water uptake. Cold summer temperatures may also damage meristematic tissues of all but the most cold hardy plant species (Brown et al. 1978b).

Climate data for the winter months are limited but mean January temperatures are estimated to be -15°C (Strong and Leggat 1981). Nocturnal temperature inversions are considered to be very common at timberline (Baig 1972).

3.1.2 Wind

Persistent strong winds are a characteristic feature of the alpine. Wind has a strong influence on snow distribution, maintaining snow-free areas on ridges and exposed slopes, and blowing snow onto leeward slopes. Plants on exposed slopes are therefore exposed to severe frost, desiccation, and abrasive damage. Plants on leeward slopes may have shortened growing seasons because of snow accumulation. Strong winds also erode fine soil particles from disturbed sites, reducing water, and nutrient holding capacities (Brown et al. 1978b). Strong winds likely result in large moisture deficits except in well protected areas or sites where groundwater discharges or snow fields

supply meltwaters. Desiccation of vegetation is enhanced by wind, especially when the ground is frozen (Strong and Leggat 1981).

3.1.3 Solar Radiation

Alpine areas receive regular diurnal and seasonal amounts of solar radiation relative to their latitude. Midsummer solar insolation often averages about 1.6 Cal cm^{-2} min^{-1} (Brown et al. 1978b). Solar radiation data for the alpine in Alberta are limited (Strong and Leggat 1981). However, in general the alpine has high solar radiation loads, which often result in high soil and plant surface temperatures, and promote summer drought and high rates of evaporation (Brown et al. 1978b; Willard and Marr 1970).

3.1.4 Frost

Frost may occur periodically throughout the growing season. On average there are 10 days with temperatures below freezing during summer in the alpine in Alberta (Table 2). Needle-ice in the soil can uproot seedlings, push rootstocks and corms out of the ground, and loosen surface layers, particularly on areas where vegetation and organic layers have been removed (Willard and Marr 1970). Frost also lowers the soil water potential, limiting water availability to plants (Brown et al. 1978b).

3.1.5 Growing Season

In Alberta, the number of growing degree days above 5°C is probably less than 500, but this will depend on slope angle and orientation (Strong and Leggat 1981). The length of the growing season is highly variable, averaging about 70 to 80 days in North America but, it may not exceed 45 days in some cases (Brown et al. 1978b). Freezing conditions may occur on many days during the growing season causing a disruption of plant growth.

3.1.6 Precipitation

Mean annual precipitation in the alpine in Alberta is about 730 mm. Precipitation generally increases from north to south (Strong and Leggat 1981). Eastward from the main ranges of the Continental Divide there is a constant decrease in total annual precipitation and in winter precipitation, and an increase in the proportion of summer precipitation. In the eastern

outermost Front Ranges, the winter precipitation has decreased to equal or less than the summer precipitation, and snowfall and total precipitation is lowest (Baig 1972). The mean May to September precipitation is 360 mm with a range of 270 to 430 mm (Table 2). In general, precipitation falls as rain from June until the first week of September, although snow can occur at almost any time during this period (Baig 1972).

Snowfall is high in the Alpine Ecoregion, with a mean of 400 mm during October to April. Snow distribution is highly variable.

3.2 TOPOGRAPHY

The Alpine Ecoregion in Alberta lies within the Rocky Mountain System. This system comprises four major subunits, from east to west: the Foothills, the Front Ranges, the Main Ranges, and the Western Ranges. Each is separated from one another by major thrust faults. The Front Ranges are oriented in a northeast-southwest direction with parallel valleys separating the ranges. Bedrock is usually dipping toward the southwest, thus providing long smooth slopes with this aspect. The northeast aspects are characteristically broken faces and cliffs. The Main Range's strata is, in general, gently dipping, with non-linear ranges with high individual or clustered peaks.

Elevations of the mountain tops generally increase from east to west from a low of 2117 m to 3100 m in the Front Ranges to heights of 3000 to 3300 m in the Main Ranges. The highest elevations occur around the Columbia Icefield, reaching from 3400 m to just over 3700 m A.S.L. The varied nature of alpine landscapes is the result of mountain building and erosion processes. In addition, the topographic features have been extensively modified by glaciation. Small glaciers still remain at high elevations, mostly near the Continental Divide. These retreating glaciers are still actively altering the landscape (Holland and Coen 1982).

3.3 DRAINAGE AND HYDROLOGY

The extensive ice and snow-fields that persist year-round at high elevations, coupled with the high precipitation, result in the Rocky Mountains being the headwaters for some of Canada's larger rivers. Although mountains comprise only 12.5% of the total drainage area, Banff, Jasper, Waterton Lakes National Parks, and the adjacent Rocky Mountains Forest Reserve, supply 87.5%

of the total annual flow of the Saskatchewan River System, the primary source of water for the Great Plains region of Alberta and Saskatchewan (Holland and Coen 1982).

Alpine watersheds are much more efficient water producers than lower elevation watersheds. Leaf (1975) calculated water production efficiencies that exceeded 90% on Colorado alpine watersheds. This efficiency is due to:

1. Large areas of fractured rock and talus slopes;
2. Poorly developed soils with high percolation and low recharge values;
3. Low evaporation and transpiration losses; and
4. Quick response time from input to outflow from the basin.

The chemical and bacteriological quality of alpine surface water from undisturbed watersheds is generally high. This is due to the generally low chemical weathering rates characteristic of cool climates and hard rock types (Retzer 1974).

Peak annual stream flow occurs 3 or 4 weeks later than at lower elevations, hence it seldom contributes significantly to flood peaks. Eighty-five percent or more of annual stream flow from the alpine zone occurs during the high water use demand period in the summer because of delayed melting of late lying drifts (Johnston and Brown 1979).

3.4 VEGETATION

Alpine plants are typically low-growing herbaceous or shrub species. Most are perennial (very few are biennial or annual) with large underground root or stem storage systems (Billings 1974b). North American alpine tundra has been described as species-poor, consisting of only 200 to 300 plant species (Brown et al. 1978b).

Vegetation of the Alpine Ecoregion in Alberta has been described in terms of altitudinal zonation (Ogilvie 1969). The Lower Alpine Subzone (ca. 2130 to 2440 m A.S.L.) comprises willow and dwarf birch communities with scattered islands of krumholz. This area is somewhat warmer than the area at higher elevations. The Middle Alpine Subzone (ca. 2440 to 2750 m A.S.L.) is characterized by relatively continuous heather and snowbed communities. The Upper Alpine Subzone (ca. 2750 to 3050 m A.S.L.) is a region of scattered

plants on rock outcrops and scree slopes. This zonation of alpine vegetation reflects the general influence of temperature and exposure to wind (Baig 1972; Strong and Leggat 1981).

Alpine vegetation typically forms a complex mosaic in which microclimatic variations are reflected by marked changes in dominant species (Holland and Coen 1982). That is, the distribution of particular vegetation types is strongly influenced by exposure to wind, snow distribution and depth, occurrence of chinooks, aspect, and soil moisture regime (Beder 1967; Crack 1977; Trottier 1972).

A generalized scheme of the more common plant communities found in the alpine in Alberta is shown in Figure 1. The following is a brief description of these plant communities.

3.4.1 Stonefields

These are found on wind exposed summits of high ridges. They are generally snow-free and confined to the Upper Alpine Subzone. Vegetation is sparse and dominated by scattered lichens attached to rock faces. *Rhizocarpon* and *Omphaldiscus* are the most abundant lichens.

3.4.2 *Dryas* Association

This association is also found in dry, wind exposed ridges. There is usually little to no snow accumulation. The dominant species is usually *Dryas octopetala*. In some Front Range sites *Dryas integrifolia* replaces *D. octopetala*. Common associates are *Empetrum nigrum*, *Salix nivalis*, *Carex drummondiana*, *Astragalus alpinus*, *Oxytropis podocarpa*, *Cetraria cucullata* and *C. nivalis*. There are extensive bare areas.

3.4.3 *Festuca* Association

This meadow type association is found on steep south-facing slopes. The daily temperatures are warmer on these aspects than other locations in the alpine. Dominant grasses are *Festuca brachyphylla*, *F. altaica* or *Elymus innovatus*. Numerous shrub and forb species are present.

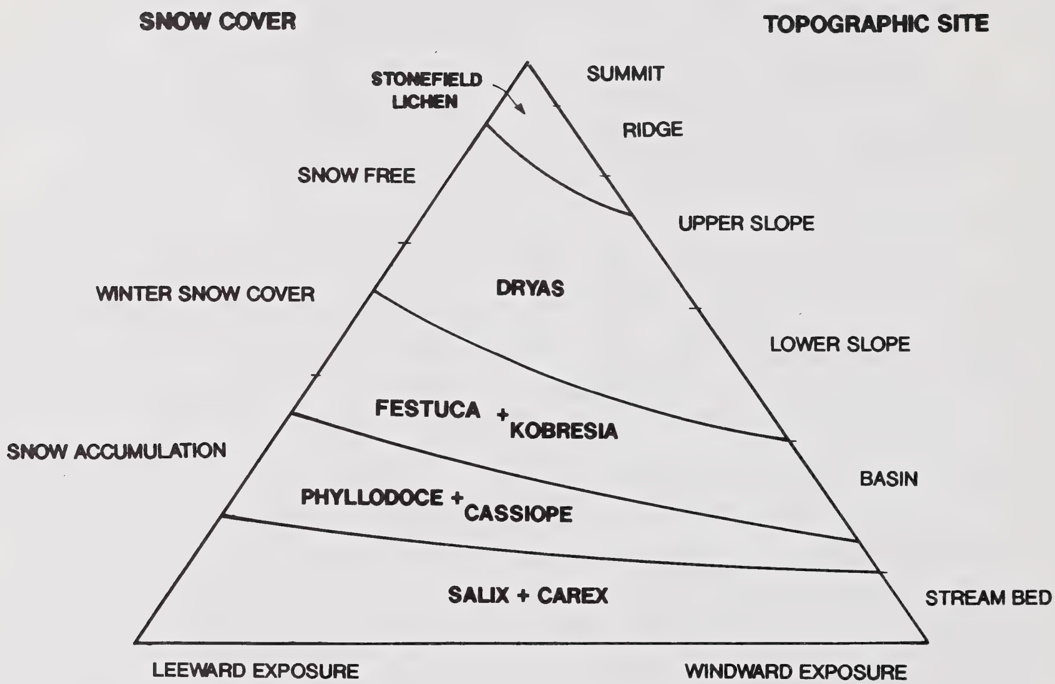

FIGURE 1 Diagrammatic representation of alpine vegetation pattern along topographic, wind and moisture gradients in Rocky Mountains, Alberta.

3.4.4 *Kobresia* Association

This meadow type is found on steep south-facing slopes, and snow-free hill tops and ridge crests. The dominant species is *Kobresia myosuroides*. Common associates are *Dryas octopetala*, *Arctostaphylos uva-ursi*, *Polygonum viviparum*, *Astragalus alpinus*, *Salix nivalis* and *Carex drummondiana*. The moisture regime is xeric to mesic.

3.4.5 *Phyllodoce* Association

This heather tundra community is found on level to steeply sloping sites of various aspects. The moisture regime is mesic with moderate snow cover. Trees are absent except for occasional *Picea engelmannii* and *Abies lasiocarpia* krumholz and tree islands at the lower elevational limits. Vegetation is dominated by *Phyllodoce glanduliflora* and *Cassiope mertensiana*. Other characteristic species include *Phyllodoce empetriformis*, *Cassiope tetragona*, *Potentilla diversifolia*, *Salix arctica*, and *S. nivalis*.

3.4.6 *Cassiope* Association

The white mountain heather community type is found on cool, moderately exposed, north-facing slopes and slope-depressions. Snow cover is moderate to deep and melts slowly. Dominant species are *Cassiope tetragona*, *Dryas octopetala* and *Salix nivalis*. Associates include *Salix arctica*, *Potentilla diversifolia* and *Festuca brachyphylla*.

3.4.7 *Salix* Association

Willow communities are found on more sheltered sites with moderate to deep snow accumulation or areas that receive seepage from late summer snowmelt and streams. Various associations have been described that are dominated by *Salix arctica*, *Salix glauca* or *Salix barrattiana*. Moisture regime varies from mesic to wet, with a variety of soil types.

3.4.8 *Carex* Association

Sedge communities are found on sites with deep snow accumulation which melts late in the summer. They are typically dominated by *Carex nigricans*. Other important species are *Antennaria lanata*, *Sibbaldia procumbens*, *Poa alpina*, *Phleum alpinum* and *Ranunculus eschscholtzii*.

3.5 LANDFORMS AND GEOMORPHIC PROCESSES

Landforms such as relic erosion surfaces (peneplains), cirque basins, ground moraines, outwash fans and terraces, solifluction terraces, and scree and rock glaciers are prominent throughout the alpine. Different types of patterned ground may be formed as the result of cryopedogenic processes. These include congelifraction (splitting of rock by frost action) and congeliturbation (stirring, thrusting, heaving, and sorting by frost activity). Subsurface rock depressions that fill with water in the warm season, may produce frost boils through the development of ice bands during rapid frost penetration in autumn and winter. Surface heave resulting from this frost penetration may exceed 30 cm in moist areas of fine grained material (Retzer 1974).

Erosion features which are common in the alpine include lobed masses of soil (solifluction terraces) or rock (rock terraces) which move downhill as the result of downslope flow of saturated soil (solifluction) or the downslope displacement of material in response to alternate freezing and thawing (frost creep). Narrow lines of rock moving downslope (rock streams) may also be present. These are thought to result from water erosion (Thilenius 1975). Runoff water resulting from summer storms and spring snowmelt can cause large quantities of soil to move downslope. Wind erosion may prevent vegetation becoming established on exposed upper slopes and ridges and result in significant soil loss. Conversely, there may be considerable loess deposition on lee slopes.

3.6 SOILS

There have been a limited number of soil surveys in the alpine in Alberta (Holland and Coen 1982; Knapik 1973; Mark 1974). In general, alpine soils are much less uniform than the soils of lower elevations. They tend to form a complex fine scale mosaic (Holland and Coen 1982). Alpine soil profiles are irregular with regard to thickness of horizon, depth to bedrock, texture and the size and amount of coarse fragments. Variations in the regolith caused by irregularities in the bedrock such as faulting are frequent and may occur abruptly. Cryopedogenic processes also result in disruptions to the soil profile (Retzer 1974).

Climate is the predominant soil forming factor with temperatures inhibiting weathering and organic matter transformations. Alpine soils in North America are characterized by a high content of weakly decomposed organic matter in the surface horizons, weak granular structure, and low clay content. (Knapik et al. 1973; Retzer 1974).

Knapik et al. (1973) noted significant relationships between plant community types, environmental parameters and soils in the Sunshine area, Banff National Park. Alpine Dystric Brunisols were typical of well drained stable slopes under mesic conditions. These soils usually had densely rooted turfs underlain by Ah horizons with high organic content. These soils were usually associated with *Phyllodoce* and *Kobresia* plant community types. Wind swept ridges which are snow-free in winter were characterized by the *Dryas* plant community type. Soils were typically Orthic Regosols. They tended to have thin sola and Ah horizons formed by the physical mixing of organic and mineral material. Soil pedons were often buried and truncated because of soil creep and frost action. On late snowbed sites, soils were also typically Orthic Regosols or Cumulic Regosols. Soil creep was active on these sites causing churning and mixing of the sola. The *Cassiope* plant community type was found on north-facing slopes. Soils here tended to have deep Ah horizons under a well-rooted turf layer. They were typically Dystric Brunisols or where soil creep was active, Orthic Regosols and Cumulic Regosols. Cumulic Regosols were also found on recent alluvium deposits. Gleysolic soils were found where there was runoff ponding and groundwater discharge.

4. DISTURBANCES TO ALPINE LANDS

4.1 DISTURBANCE TYPES AND LOCATIONS IN ALBERTA

The Alpine Ecoregion in Alberta is presently affected by the following land-uses: watershed protection, wildlife habitat, recreation, and natural gas production. The following sections provide a brief description of various types of disturbance and where these occur within alpine areas of Alberta. A summary of this information is provided in Table 3.

4.1.1 Mining

There are presently no mining activities in the alpine in Alberta.

4.1.2 Exploration

Exploration activities for oil and gas in the alpine are confined primarily to southern Alberta. There has been historical coal exploration in the alpine near Grande Cache. At present, there are no mineral exploration activities in the alpine in Alberta.

4.1.3 Recreation

Disturbance to the alpine caused by recreation is largely associated with development and use of ski facilities and hiking trails. In Alberta, these uses are primarily concentrated in Banff and Jasper National Parks.

Development of ski facilities can cause significant impacts during the construction phase, which includes:

1. Construction of access roads;
2. Terrain modification at tower bases and at upper and lower terminals;
3. Recontouring ski runs;
4. Removal of hazards such as rocks; and
5. Installation of pipelines for snow making.

Winter operation of the skiing facilities may also cause impacts to the alpine environment. Skiing and slope grooming may cause significant changes in the structure, density, and depth of the snowpack. This alteration of snow

Table 3. Types of disturbance in various alpine regions in Alberta

	Provincial Forests				National Parks			Kananaskis	Provincial Wilderness Areas			
Disturbance Types	Bow/Crow	Rocky/ Clearwater	Edson	Grande Prairie	Jasper	Banff	Waterton	Provincial Park	Willmore	Kakwa	Siffleur	White Goat
Mining	No	No	No	No	No	No	No	No	No	No	No	No
Exploration	Yes	No	No	No	No	No	No	No	No	No	No	No
Recreation	Yes	Yes	Yes	Yes	Yes[a]	Yes[a]	Yes	Yes[a]	Yes[b]	Yes[b]	Yes[b]	Yes[b]
Road Construction	Yes	No	No	No	Yes	Yes	No	Yes	No	No	No	No
Pipelines/Powerlines	Yes	No	No	No	Yes[a]	Yes[a]	No	Yes[a]	No	No	No	No
Grazing	No	No	No	No	No	No	No	No	No	No	No	No

[a] These disturbances are linked to the construction of ski resorts.

[b] Only non-motorized recreational use allowed.

deposition and melting may cause significant impacts on vegetation, soils, and the hydrologic regime of watersheds (Hamilton 1981).

Alpine hiking trails in Banff and Jasper National Parks have received considerabe use in the last decade. Increased access to alpine areas has been created by the construction of gondola lifts and the opening of ski resorts for summer use. The majority of the disturbance caused by hiking is associated with construction of trails and off-trail use.

Outside of National Park boundaries, recreation activities are the primary source of disturbance in the alpine. The following forest districts within the Bow/Crow Forest Region were contacted for information about types of disturbance in the alpine: Blairmore, Elbow, Ghost, Sundre, and Turner Valley.

In the Blairmore Forest District, use of all-terrain vehicles (ATV's) in alpine areas is most common near the source of the Oldman River and at Corner Mountain. Commercial trail riding operations also utilize the alpine zone in this district. In the Elbow Forest District, alpine recreation activities are associated primarily with elk and bighorn sheep hunting. In the Ghost Forest District, all recreation activities are reported to be carefully monitored and maintained below treeline. At Sundre Forest District, recreation activities predominantly include use of equestrian trails at Ice Lake and Destination Point. Occasional sheep hunters are also observed in the alpine in this area. In Turner Valley Forest District, major recreation activities include sightseeing, sheep hunting, and random camping around alpine lakes.

In the Edson Forest Region, ATV use is frequent in the alpine at Mountain Park southwest of Robb, and in the Cardinal Divide area. Back-country camping and use of equestrian trails is also frequent in the Willmore Wilderness area, however recreation activity is primarily concentrated in valley bottoms. In the Rocky/Clearwater Forest, commercial trail riding operations represent the major alpine use.

4.1.4 Others

4.1.4.1 Road construction. Disturbance caused by road construction is limited in the alpine and is primarily associated with roads leading to

forestry fire towers, or with maintenance roads at ski resorts in the national parks. In the Blairmore Forest District, access roads to the following fire towers are located in the alpine: Sugarloaf, Livingstone, Ironstone, and Carbondale. The access road to the Shell/Waterton gas field at Prairie Bluff is also located in the alpine.

In the Elbow Forest District, access roads leading to Moose and Kananaskis lookouts are located in the alpine, while in the Ghost District, the Burnt Timber Tower road is abandoned but as yet, unreclaimed.

4.1.4.2 Pipelines and powerlines. Part of the gas gathering system associated with the Shell/Waterton gas field at Prairie Bluff is situated in the alpine. The Kanelk powerline crosses the continental divide at the foot of Elk Lake in Kananaskis Provincial Park, and a 500 Kv powerline crosses the Livingstone range into British Columbia in the Crowsnest Pass area.

4.1.4.3 Grazing. Grazing by domestic livestock is not encouraged above 1,500 m in the eastern slopes of Alberta (Mr. Calvin Duane 1990; Personal Communication). Grazing, therefore, is not a significant disturbance in alpine areas in Alberta.

4.1.4.4 Natural causes of disturbance. Natural causes of large-sacle disturbance to the alpine zone are associated with the incidence of fire, landslides or avalanches. Disturbances on a smaller-scale include small mammal burrowing and tunnelling (Thorn 1982), and freeze thaw cycles (Brink 1964; Johnson and Billings 1962). All of these can have a significant impact on vegetation cover in the alpine and should be considered in reclamation planning.

4.1.4.5 Historical causes of disturbance. Historical disturbances to the alpine include mining activity at Byron Creek south of Hillcrest in the Blairmore Forest District. The collapse of workings at this mine has resulted in disturbance to the alpine in this area. Historical coal extraction was also located at Panther Corners and the Ya Ha Tinda area in the Sundre Forest District, and at Mountain Park in the Edson Forest Region.

4.2 ENVIRONMENTAL IMPACTS

The following section describes the impacts associated with various types of disturbances in the alpine. Because of the limited amount of information on impacts to the alpine in Alberta, studies from the United States have also been reviewed.

4.2.1 Impacts Caused by Mining

Alpine areas above 2333 m in the Rocky Mountains of Alberta provide winter range for most of the mountain goat and some bighorn sheep herds (Etter 1973). Disturbance caused by mining could temporarily destroy winter habitat areas for these species.

Brown et al. (1978a) have described impacts to the alpine environment caused by mining disturbances in the western United States. Removal of vegetation, organic matter, and surface soil resulted in increased potential for wind and water erosion. Mass slumping may occur from mine dump head cuts and steep faces. Billings (1978) reported that soil characteristics, including nutrient status, pH and moisture content may be altered by mining in the alpine. Vegetation composition will also likely change since certain native species will not likely re-establish, weeds may invade, and exotic species may be introduced during revegetation.

Watersheds may also be impacted by increased sediment loads (Brown et al. 1978a). Watercourses may also be altered and aquatic environments damaged from oil and/or other petroleum product spillage during exploration and mining operations. Patterns of drift snow and resultant snowbeds may be altered as a result of topographic changes.

4.2.2 Impacts Caused by Exploration

Impacts from exploration activities in the alpine are related to construction of drill pads, spur roads and exploration trenches. In general, the extent of individual disturbances associated with exploration is relatively small - usually occupying less than 1 ha (Brown et al. 1978a).

Watersheds may be impacted by increased sediment loads resulting from soil erosion during construction of drill pads, spur roads and exploration trenches. Impacts on wildlife from exploration activities include decreased available winter range from unreclaimed exploration sites, and

displacement from habitat because of disturbance. Other impacts associated with exploration include destruction of vegetation from vehicular traffic, alterations in soil thermal and water regimes, and changes in nutrient status of soils (Brown et al. 1978a).

4.2.3 Impacts Caused by Recreation

Development and use of recreation facilities can result in a variety of impacts. These are associated with off-road vehicle use, equestrian trail use, summer hiking, camping, and construction and maintenance of ski facilities.

4.2.3.1 Off-road vehicle use. Impacts resulting from off-road vehicle use include stream sedimentation, erosion, slumping, and vegetation removal. Studies reporting the effects of ATV use in the alpine are limited.

Greller et al. (1974) reported on the impacts of snowmobile use in the alpine at Niwot Ridge, Colorado, during limited snowfall winters. Impacts included soil scraping, removal of lichens, and damage to *Selaginella densa* and other taller plants from skis and rubber treads. Soil gouging, stem breakage, and leaf crushing resulted from the weight of the snowmobile and driver. Entire plant removal occurred in areas of snowmobile start-up or rapid acceleration. Plants most susceptible to damage caused by snowmobiles were: *Arenaria obtusiloba; A. fendleri; Paronychia sessiflora var. pulvinata; Silene acaulis; Eritrichium aretioides; Phlox pulvinata; Selaginella densa; Hymenoxys acaulis. Kobresia myosuroides* in isolated tussock communities was very susceptible to damage. However, where *Kobresia* occurred as a mature, closed-meadow community, it was less susceptible to damage.

4.2.3.2 Equestrian use. Price (1985) compared trampling damage to vegetation caused by horses with that caused by hikers. Vegetation damage caused by horses was much higher because of increased ground pressure, trail widening, and shortcuts through wet meadows. Loosening of soil and vegetation along trails was caused by pack animals dragging their feet. Trampling impacts from horse use tended to be more localized and severe than those caused by hikers.

Horses can also cause damage to vegetation by grazing. The degree of grazing impacts on alpine vegetation depends on a number of variables:

1. The resistance of the vegetation to grazing;
2. The area to which grazing is restricted;
3. Palatability of available species;
4. Frequency of grazing in a given area;
5. Phenological stage of grazed plants; and,
6. The amount of supplemental feeding provided to pack animals.

Recovery of over-grazed areas is often limited unless horse use is excluded from those areas.

Exotic species may be introduced to the alpine through the use of hay for supplemental feeding of pack animals. Exotic species are not likely to survive alpine climatic conditions, except on frequently disturbed sites (trail sides or corrals) where there is a competitive advantage over native species. The introduction of exotic species as a result of supplemental feeding of pack animals may be limited through the use of pelleted feeds.

Concentrated use of horses near lakes and watercourses may cause sedimentation and increased bacteriological counts in the water (Brown et al. 1978a).

4.2.3.3 Hiking trail development and use. Impacts on alpine areas caused by hiking are primarily associated with trail construction and off-trail use. Price (1981) has ranked the susceptibility of various plant communities at Sunshine Village to trail development (Table 4). Soil moisture regime of a plant community was considered the most important variable to be considered when determining the susceptibility of vegetation to damage.

In Banff and Jasper National Parks, some hiking trails have seriously deteriorated as the traffic flow increased, particularly in wet areas and areas with late-lying snowbeds. The vegetation cover may be completely worn away exposing the soil. Trails may become impassable because of mud or because soil erosion has exposed a rough and hazardous bed of rocks. Trails may also become braided where hikers have taken shortcuts or walked alongside the original trail (Walker and Harrison 1986).

Table 4. Susceptibility of vegetation to trail development. Rank 1 is most susceptible, rank 6 is least susceptible.

Rank	Dominant Species
1	*Carex nigricans/Salix arctica*
2	*Phyllodoce glanduliflora*
3	*Carex nigricans/Antennaria lanata*
4	*Antennaria lanata/Carex nigricans*
5	*Carex nigricans; Antennaria lanata/Salix arctica*
6	*Dryas hookeriana*

Source: Price (1981)

Hiking trails which cross a natural drainage channel can alter the normal flow pattern of water from snowmelt. Water can be intercepted and channelled down the trails. This can lead to erosion of soil from the trail and render the trail difficult to use. This may be particularly evident where trails are formed on organic soils (Walker and Harrison 1986).

Willard and Marr (1970) studied alpine tundra which had been trampled by visitors to Rocky Mountain National Park in Colorado. Most trampling occurred where visitors took shortcuts to and from points of interest. Plants in trampled areas were first bent, then broken, and finally killed. If trampling continued, the plant cover and eventually the more friable uppersoil layers, were churned up and then eroded away by wind and running water. Once the turf was broken, erosion processes eventually removed the entire humus-enriched soil horizons and left a surface covered with coarse gravel.

Willard and Marr (1970) concluded that:

1. Occasional trampling had no persistent visible effects;
2. Trampling by fewer than five persons every few days over a period of many years had little or no persistent visible effect;

3. Trampling by hundreds of people in one area would destroy a fell-field ecosystem in 2 weeks, a snowbed ecosystem in from 1 to 3 weeks, and a turf ecosystem in 8 weeks; and,
4. Soil moisture greatly increased the susceptibility of ecosystems to damage from trampling. Snowbeds and marshes were easily damaged by only a small amount of walking.

4.2.3.4 Sensitivity of plants to trampling. Willard (1963) observed visitors walk across several snowbed associations. As a result of trampling, plants were damaged because of the wet, easily compacted soil. Young succulent plants at the edge of melting drifts were particularly susceptible to trampling. Mature plants, which are normally resistant to trampling, were susceptible to breakage under the snowbed site because there they tend to be large, succulent, and brittle. Plant recovery was poor on snowbed sites because of the short growing season. Since natural vegetation cover is sparse on these sites, the reduction of plant cover was conspicuous.

Bell and Bliss (1973) determined the effects of trampling on alpine plants in an area of Olympic National Park in Washington, United States. Groups of 5 m long transects were set up in: (1) a snowbank community dominated by *Antennaria lanata* and *Carex sigricous*, and (2) a stone-vegetation stripe community containing *Lupinus lepidus*, *Carex phaeocephala*, *Phlox diffusa var. longistylis*, and *Arenaria obtusiloba*. Each transect was walked along 0, 5, 25, or 100 times daily on three consecutive days per week for 4 weeks. Plant cover was determined before and immediately after trampling, and 1 year after trampling. Plant productivity was assessed from clip plots made at the end of the first growing season.

Although both communities showed only slight apparent damage with five passes daily, differences were nevertheless evident. Paths were more obvious in the snowbank site because *Antennaria lanata* was easily crushed and failed to recover after damage. *Carex nigricans* survived trampling longer than *A. lanata*. Loss of cover and annual production was apparent. At this level of trampling, cover was reduced by 5%, and annual production by 46% for the snowbank community, and by 24% and 47% respectively for the stone-vegetation stripe community. Paths remained visible 1 year after trampling in areas of both communities receiving 300 and 1200 total walks.

Achuff (1985) has used transects to measure the impact of off-trail use on alpine vegetation at Sunshine Meadows, Banff National Park. The transects consisted of twenty 1 m^2 plots. Ten "impacted" plots were placed parallel to the trail (five on each side), 25 cm from the trail edge. A comparison of plant cover and species composition between the impacted plots and control plots was used to provide an estimate of effective change caused by trampling.

The Canadian Parks Service has established limits to effective change in the Sunshine Meadows:

1. A reduction in the value of Cover Reduction (CR) by 10%. Where

$$CR = \frac{(Cu - Ci)\,100}{Cu}$$

Cu = sum of mean cover of species in non-impacted plots
Ci = sum of mean cover of species in impacted plots

2. An increase in the value of soil plus rock cover by 10%.
3. A change in the relative percentages of the three life forms (forb, graminoid, dwarf shrub) by 30% (Westhaver 1983), as determined by summing the absolute values of the changes.

Achuff (1985) found that dwarf shrub species tended to be the most sensitive to trampling, with upright species less durable than prostrate species (Tables 5 and 6). Forbs are the next most sensitive group with the taller, larger leaved species less durable than prostrate, smaller leaved species. Most durable are sedges and grasses.

Lichens were also found to be sensitive to trampling. Mosses tended to decrease with increased trampling, however, cover of *Polytrichum juniperinum* appeared to increase on lightly trampled plots.

4.2.3.5 <u>Recovery of trampled areas</u>. Willard and Marr (1970) observed the recovery of trampled areas after enclosures had been constructed to exclude visitors. Tundra subject to a single season of intense walking recovered to its natural form after two growing seasons. An area subject to trampling for 26 years was observed over a 4 year recovery period. Although groundcover had been reduced by trampling to approximately 50%, the total number of species

Table 5. Sensitivity of various vegetation types at Sunshine Meadows to disturbance by trampling.

Rank	Vegetation Type
Most Sensitive	*Phyllodoce glanduliflora - Cassiope mertensiana - Antennaria lanata*
	Erigeron peregrinus - Valeriana sitchensis
	Antennaria lanata - Vaccinium scoparium
	Salix arctica - Potentilla diversifolia
Least Sensitive	*Dryas octopetala - Salix nivalis*
	Carex nigricans - Antennaria lanata

Source: Achuff (1985)

Table 6. Sensitivity of various plant species to trampling based on cover reduction.

Rank	Species
Most Sensitive	*Phyllodoce glanduliflora, Vaccinium scoparium, Cassiope mertensiana, lichens*
	Salix arctica, Salix nivalis, Dryas octopetala
	Trollius albiflorus, Erigeron peregrius, Potentilla diversifolia
	Fragaria virginiana, Sibbaldia procumbens, Antennaria lanata
Least Sensitive	*Carex nigricans, Poa alpina, Phleum alpinum, Juncus drummondii, Carex nigricans, Antennaria lanata*

Source: Achuff (1985)

present was within the normal range for stands of the *Kobresia* association. Erosion of soil by snowmelt water in spring, by rain in summer and by wind throughout the year (but especially in late summer and autumn), was evident during the recovery period. Soil erosion was exacerbated by needle-ice activity, which was especially active in the bare organic-rich A horizon. Needle-ice uprooted seedlings, pushed rootstocks and corms out of the ground, and loosened the surface layers of soil.

The recovery of cushion plants varied among the different species. The damaged parts of *Silene acaulis* remained hard, compact, and devoid of invasion by seedlings for years after the cessation of disturbance. However, the damaged surfaces of *Minuartia obtusiloba* and *Trifolium dasyphyllum* were invaded by runners growing from undamaged parts of the cushion.

The susceptibility of various plant species to trampling is influenced by season of hiking use, duration of use, and intensity of use. Harrison (1982) has summarized information on the susceptibility of several Alberta plant species to trampling (Table 7).

Table 7. The susceptibility and resistance of selected plant species to trampling.

Species	Susceptible	Resistant
Antennaria lanata		X
Carex nigricans		X
Cassiope mertensiana	X	
Phleum alpinum		X
Poa alpina		X
Phyllodoce empetriformis	X	
Phyllodoce glanduliflora	X	
Salix arctica	X	
Trisetum spicatum	X	
Vaccinium scoparium	X	

Source: Harrison (1982)

Secondary succession of severely trampled areas tended to be very slow and Willard and Marr (1970) estimated that it would take at least several hundred years for a climax ecosystem to develop on those areas. The most favourable place for seedlings to develop was the margins of established

plants. Bare humus supported the fewest seedlings because of needle-ice activity in spring and fall, and its susceptibility to desiccation under high summer temperatures. The survival of seedlings that did germinate in bare soil was greater on exposed B and C horizons than on the A horizon. Some plant species invaded the exposed soil areas, including *Minuartia rubella*, *Draba crassifolia*, *D. nivalis*, *Stellaria umbellata*, *Artemisia scopulorum*, *Mertensia viridis*, *Ledum lanceolatum*, and *Bistorta bistortoides*.

4.2.3.6 Camping. Impacts to the alpine caused by camping are associated with the following activities (Price 1985):

1. Covering of vegetation by tents;
2. Fire-ring creation; and,
3. Trail development.

Price (1985) studied impacts caused by camping on a *Carex nigricans* meadow in Yoho National Park. Impacts were insignificant at campsites established for a week or less. Long-term or frequent camping resulted in destruction of vegetation, and soil compaction. Plant aerial parts, and plants in flower were most susceptible to damage caused by camping.

Other impacts associated with camping include rock removal, littering, and excavation of pits for garbage disposal. In the United States, Brown et al. (1978a) reported that water quality reduction because of inadequate sanitation facilities at frequently used remote sites was a widespread problem.

4.2.3.7 Construction and operation of ski field facilities. Construction of ski field facilities can cause damage to alpine plant communities. Meadow and snowbed communities which have been damaged by construction activity can be susceptible to erosion (Hamilton 1982). Terrain modification for construction of ski facilities (lift towers, terminals) and ski runs will cause disturbance to vegetation and soils. This is particularly evident where terrain modification is carried out to produce a grade suitable for T-bar development (Fitzmartyn 1976). Naschberger (1988) reported that the high humus content of alpine soils is lost almost completely during ski slope grading. In most cases, less than 10% of the original content was left after grading. These disturbed areas may be susceptible to erosion and the resulting sediment

washed downslope may cause plant burial. Bare areas may also be susceptible to needle-ice and prove difficult to revegetate.

Downhill skiing and snow grooming can result in significant changes in snow distribution, layering, and density. Fitzmartyn (1976) found at Sunshine Ski Resort, Banff National Park, that the density of snow was higher in skied areas due to compaction on the runs. Ice layering in the snow was also much more prevalent within areas being skied. This change in the snowbed has the potential to cause significant changes to vegetation. Late snowbed sites typically have sparse vegetation cover. In steep locations, skiing activity can shear off the tops of hummocks. This may result in soil erosion. Fitzmartyn (1976) found that the white heather community, the mountain heath community, the mountain avens community, and the snowbed sedge community had been directly affected by skiing activity.

Watersheds may be impacted by ski facility construction through increased stream sedimentation during ski slope grading; streambank erosion may also occur as well as possible stream diversion during the grading process. Changes in the snowpack on ski runs may cause a change in the rate of snowmelt. This may result in a change in the hydrology of an entire watershed, particularly where soil conditions promote rapid drainage to other discharge areas.

Snowmaking will increase the depth and density (water content) of the snowpack. This may result in a later snow release date, colder temperatures beneath the snowpack and increased volume of meltwater. This may lead to changes in plant communities, nutrient cycling, and soil erosion (Achuff and Knapik 1990).

Critical winter ranges for wildlife may be encroached upon by ski hill construction.

The review process for developments in downhill ski hill areas in the western National Parks includes preparation of environmental impact assessments. These assessments include specific mitigation requirements, including reclamation of disturbances resulting from construction and operation of the ski area. Further information can be obtained from the following reports: Beswick (1989); Canadian Parks Service (1989); Environmental Management Associates (1987); Leeson (1986); and, Leeson and Isrealson (1982).

4.2.4 Impacts Caused by Other Disturbances

4.2.4.1 Road construction. Disturbance to the alpine associated with vehicle use includes both road construction and off-road vehicle use. Impacts from the latter are discussed in section 4.2.3.1.

Road construction in the alpine may result from exploration activities, scientific endeavours, mining, and recreation. Impacts range from minimal soil and vegetation compaction to removal of organic and surface soil horizons. Greller (1974) identified various impacts to alpine tundra as a result of road construction:

1. Loss of tundra vegetation on the road bed site;
2. Exposure of subsoil and rock to the harsh climate; and,
3. Creation of topographic conditions that are unique to the site (e.g., changed drainage pattern and creation of steep slopes).

During road construction, soil thermal and water regimes are altered, and nutrient status and site productivity are lowered. Brown et al. (1978a) also reported that thermokarsting resulting from soil compaction was a problem in areas of high water table.

Road construction may impact watersheds by altering stream courses and rates of flow, increasing stream sedimentation, and increasing streambank erosion during the construction phase. Fish spawning sites may also be detrimentally affected by increased stream sedimentation.

Wildlife may be indirectly impacted by road construction as a result of increased disturbance associated with road use.

4.2.4.2 Grazing. Impacts of grazing in alpine zones are related to heavy grazing pressure and poor management practices. Soil erosion may result because of depleted vegetation cover and soil compaction. Watersheds may be subjected to increased sediment loads and bacteriological counts due to concentrated animal use (Brown et al. 1978a). Wildlife may also be impacted by domestic grazing because of competition for forage. Impacts to tourism include a decrease in aesthetic appeal of back-country areas because of the presence of domestic livestock. In Alberta, domestic grazing in the alpine is

primarily associated with recreational horse use, the specific impacts of which are discussed in section 4.2.3.2.

4.2.4.3 Pipelines and powerlines. The impacts associated with construction of powerline support towers and installation and maintenance of powerlines are considerably lessened if construction of these lines is helicopter assisted. Machinery installed lines may result in soil compaction and erosion on sites adjacent to the line. Vegetation and soils are removed at support tower sites. In the Crowsnest Pass area, a 500 Kv line extending over the Livingstone range into B.C. was machinery installed and successfully reclaimed (Mr. Bill Sutton 1990; Personal Communication).

Pipeline impacts are more severe than powerline impacts. Pipelines require trench excavation for pipe installation. This procedure removes vegetation and disturbs soils. Erosion from bare soil may occur, which may subsequently result in stream sedimentation. Introduction of exotic species and a decrease in native species may also occur during revegetation procedures. Wildlife may be disturbed during the construction phase, and the increased palatability of exotic plant species used for revegetation may attract some ungulates to the pipeline after revegetation. Both pipelines and powerlines may reduce the aesthetic appeal of the pristine alpine environment.

4.2.4.4 Natural causes of disturbances. Impacts resulting from natural causes of disturbance to the alpine are associated with fire, landslides or avalanches, small mammal burrowing and tunnelling (Thorn 1982), and freeze-thaw cycles (Brink 1964; Johnson and Billings 1962).

Depending on the fire intensity, vegetation and organic matter may be removed. Thawing and slumping of frozen soils may also result. Current studies indicate that the impact of fire on watershed hydrology is relatively minor and fairly short-lived. Siltation resulting from increased erosion activity in burned-over areas is the greatest factor. During fire suppression, use of chemical retardants containing detergents, ammonium sulphate or ammonium phosphate may contaminate critical watersheds.

Landslides and avalanches are fairly common in the alpine environment. These bury soil and vegetation and present an infertile growth medium

for subsequent colonization. Siltation and watercourse alteration, as well as increased wind erosion of fine particles may result from these disturbances.

Less significant natural causes of disturbance include mammal activities (burrowing and tunnelling) and freeze-thaw cycles. Soils exposed by mammal activities may result in subsequent erosion. Freeze-thaw cycles can uproot established seedlings making them susceptible to desiccation on exposed, fine-textured soils.

4.2.5 Visual Impacts

Trottier and Scotter (1975) found that in excess of 40% of the back-country users sampled in a survey at Banff National Park noted "scenery" as the most enjoyable aspect of their trip. Any development in the alpine should therefore, include consideration of the resulting visual impacts as part of the environmental impact assessment process. Since alpine sites are visible from long distances, visual impact analyses must take into account the on-site impacts as well as the impacts as seen from a distance.

5. RECLAMATION

5.1 RECLAMATION PLANNING

Effective reclamation of disturbed alpine lands is very much dependant on thorough planning.

The main constituents of a reclamation plan are:

1. Determination of reclamation goals;
2. Description of existing site conditions;
3. Site preparation (establishment of final landform);
4. Surface preparation (soil reconstruction);
5. Revegetation; and,
6. Maintenance of reclaimed land.

Each of these constituents requires detailed planning and are discussed in this section.

5.2 RECLAMATION GOALS

Reclamation goals are dependant on the type of disturbance and the choice of post-disturbance land-use. The goal of reclamation in Alberta is return of equivalent capability. Within the National Parks, the goal is similar, however the focus is much more closely tied to the return of native species and original use (i.e., restoration).

5.2.1 Erosion Control and Slope Stability

Most reclamation programmes have an immediate goal of providing protection and surface stability to disturbances. This is to reduce erosion while still providing for the movement of water off-site. It is important that reclamation planning includes provision for an integrated and detailed drainage and erosion control scheme. Soil erosion can be reduced by minimizing the time that reclaimed surfaces are left bare. This can be achieved by careful scheduling of site preparation, surface preparation, and seeding or planting operations. Minimization of slope angles, and slope lengths, will help reduce erosion risk.

5.2.2 Aesthetics

Reclamation planning should also consider means of reducing the visual impact of a disturbance, both from an on-site and an off-site perspective. This includes the restoration of landscape character and scenic values. This is particularly important in the National Parks where there is a need to preserve the attractive qualities of a wilderness environment.

5.2.3 Wildlife Habitat

Alpine lands provide important winter range for most of the mountain goats and some bighorn sheep herds in Alberta (Etter 1973). Elk may also utilize these areas. Planning for ungulate range must use plant species adapted to the alpine areas as well as being desirable forage. Steep south-facing slopes that are windswept will tend to remain snow-free during winter and receive the heaviest utilization. Plant species chosen for these areas will need to be drought tolerant as well as winter hardy.

5.2.4 Recreation

Use of alpine lands for summer and winter recreation use is increasing rapidly in Alberta. The primary reclamation goals in these areas is to minimize environmental impacts associated with recreation use and to establish maintenance-free native vegetation on damaged areas.

Hiking trail reconstruction needs to be planned prior to work commencing. Factors that need to be considered include determination of visitor usage patterns, type of use (horse, hiking), and the number of visitors anticipated to use the trail. If several routes are used it is important to determine the most heavily used alternative so it can be upgraded and the others closed and revegetated; however, there are some "short-cuts" that should not be trails and other factors must enter into the decision to choose the best trail (Walker and Harrison 1986).

5.2.5 Restoration

The main focus of Alberta legislation is on reclamation; that is the return of disturbed land to some equivalent land capability. However, in North America the most common long range goal of revegetation on alpine disturbances is the establishment of plant cover similar to surrounding

undisturbed plant communities (i.e., restoration). This is the most practical approach because extreme conditions in the alpine limit the choice of land-use alternatives.

5.3 DESCRIPTION OF EXISTING SITE CONDITIONS

A description of site conditions prior to disturbance provides a standard against which to determine the success of a reclamation programme in achieving the desired post-disturbance land capabilities. This baseline information includes data on slopes, elevations, aspects, drainage patterns, vegetation, and soil conditions. Soils information can be used to determine the need for amendments or to select soils suitable for salvage.

Surface features such as slopes, elevation, aspect, and drainage patterns have an important influence on successional patterns and on local populations of adapted species. Vegetation baseline studies as described by Ward (1974) prior to revegetation have been recommended by Brown et al. (1976) for alpine areas. Alpine environments represent the ecological limits of many species and spatial environmental gradients have a large influence on plant distribution. Vegetation baselines provide information about the best adapted combination of species for a given set of environmental conditions. They can also identify areas that are susceptible to disturbance (Webber and Ives 1978), endangered plant species, and the relationship of wildlife to environmental gradients (Ward 1974).

On a given alpine site, the local distribution pattern of plants is strongly influenced by topography through its influence on solar radiation, soil moisture, soil and air temperatures, and both the abrasive and protecting aspects of snow. These interact to produce what is essentially a combination of an alpine moisture gradient and a length of growing season gradient caused by differential snowmelt. Topography, through its control of snow distribution, is also an important factor in controlling soil distribution and development in the alpine.

Burns (1980) developed a conceptual alpine slope (Figure 2) as a means of land-use planning in the alpine. The slope consists of seven management units. Extremely windblown (EWB) and windblown (WB) sites found on alpine ridges and knolls are very dry, sparsely vegetated, and subject to wind erosion. Snow cover is rare on these sites. Minimal snow cover portions of

the slope (MSC) receive the greatest loess deposition and occur in cols and on large plateaus. Early melting snowbank sites (EMS) are found at lower elevations and generally melt out by June. Late-melting snowbank sites (LMS) normally melt out in July or August, whereas perennial snowbanks (PS) rarely melt out completely. All three of the snowbank sites (EMS, LMS, PS) continually undergo downslope movement. Below each snowbank site is a wet meadow where meltwater accumulates.

The minimum snow cover and the early melting snowbank sites provide the greatest stability and best conditions for soil and plant development. These slope positions receive enough snow cover for plant moisture but not too much to shorten the growing season. The partial snow cover also reduces the potential for winter frost processes in the soil.

Because of the diversity of sites in the alpine, reclamation methods should be developed for each particular snow cover site. The concept of the alpine slope can be used to divide an area into appropriate management units for the purposes of reclamation planning.

5.4 SITE PREPARATION

Site preparation involves a number of practices with the objective of modifying site conditions to conform to the post-disturbance land-use and in preparation for soil replacement and revegetation.

5.4.1 Site Contouring

Contouring in mountainous areas is a critical operation because of the steep terrain and potentially erodible nature of the soils. Creation of stable slopes is necessary before a permanent vegetation cover can be established. The revegetation of steep south and west-facing slopes is often difficult in the alpine because of high surface temperatures produced by heavy direct insolation. Reduced slopes will help mitigate this effect.

Contouring a site to maximize the area of minimum snow cover and early melting snowbank sites will enhance conditions for revegetation.

5.4.1.1 Contouring for large scale disturbance. Brown and Johnston (1978) found shaping and contouring to be important steps in reclamation on a large scale rehabilitation trial in the subalpine-alpine transition zone in the

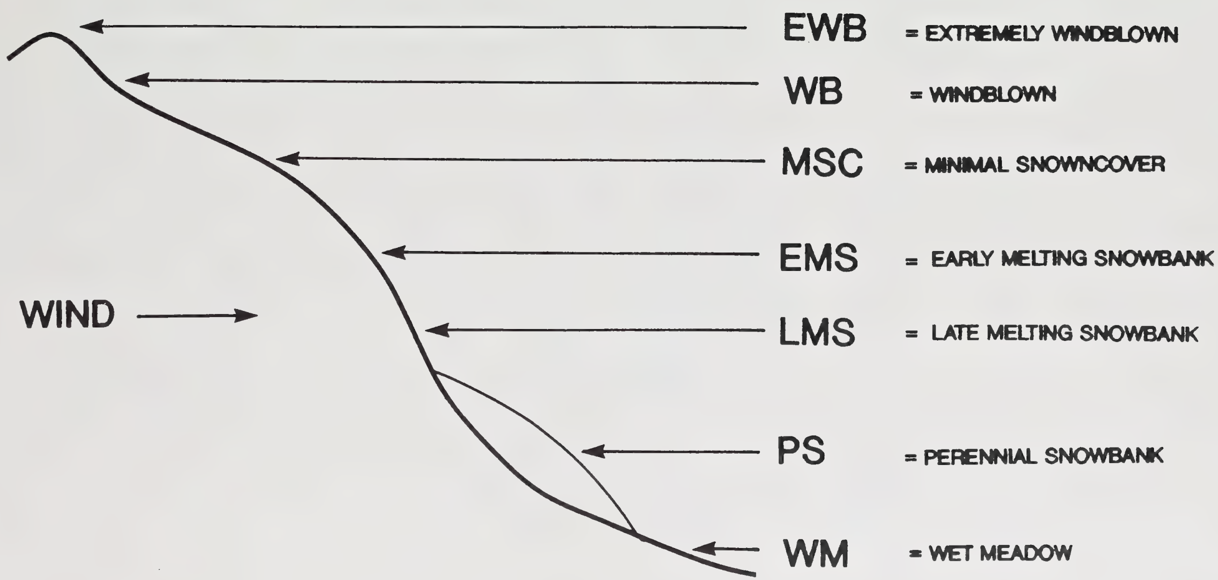

FIGURE 2 Conceptual alpine slope. Positions on the slope are determined by snow cover. The windward slope has the same sequence but lacks the snowbank and the late melting snowbank (modified from Burns (1980)).

Beartooth Mountains of Montana. The site was rough-graded and contoured to conform to the natural topography of the area. This shaping and contouring procedure eliminated ridges (alpine ridges tend to scour in winter and become very dry during the summer). Contouring also removes depressions that become pockets of deep snow accumulation. After contouring, snow distribution was more even, which appeared to promote uniform infiltration of snowmelt water, a more regulated rate of runoff, and evenly distributed plant emergence and development.

Jones et al. (1973) tested the effectiveness of small terraces for revegetating steep mountain slopes (greater than 33°) near Beckley, West Virginia. A series of terraces were constructed with hand tools about 45 cm to 60 cm apart down the slope. Legumes were seeded or transplanted on the terraces. Assessments were made of plant establishment after one and two growing seasons.

Plants established on the terraces appeared to protect the slopes and facilitate a full plant cover. The authors considered that the terraces improved moisture infiltration, and retention of seed, lime, and fertilizer.

However, Brammer (1978) considered that soil movement down the short faces and deposition on flat benches may retard revegetation. The entrapped silt on the benches may smother emerging plants. The terraced slope is not stable until it has weathered to a concave shape.

Natural slopes within any given area tend to have concave profile shapes. The slope tends to become progressively flatter towards the bottom so that water velocity downslope is always maintained below values where erosion can begin. Reshaping slopes with slightly concave shapes will, therefore, help reduce water runoff velocity and consequent erosion.

5.4.1.2 Contouring for road construction. Gregg (1976) described site preparation procedures conducted during construction of Vail Pass roadway (3500 m A.S.L.) in Colorado. The majority of slopes were laid back to 2:1 (horizontal to vertical) with some slopes laid back to 3:1. He noted that revegetation was more easily accomplished on flatter slopes, however, the additional grading required created more ground disturbance.

Rounding of the tops of cut slopes enhanced stabilization and revegetation procedures and helped the road cuts blend with the adjacent natu-

ral mountain terrain. It also eliminated the natural undercutting action at the top of cutslopes by smoothing the transition between natural and created slope edges.

Slope grading techniques adopted by the Colorado Department of Highways for reclaiming roadsides in the Vail Pass area were described by Tupa (1978). Slope exposures are limited to ten vertical metres before topsoil placement and revegetation. Reduced slope exposure allows for easier topsoil placement, more efficient mulching and seeding operations, and prevents disturbed areas from being left disturbed for the duration of the project.

5.4.2 Slopes

Nishimura (1974) considered that maximum slope on which to grow grass on small areas was about 1.5:1 (horizontal to vertical). A slope of 2:1 was considered better for successful grass establishment on large areas. It was found easier to establish grass cover on a fill than on a cutslope.

On slopes steeper than 1:1, it is probable that topsoil will slump off during the saturation period in the springtime (Welin 1974).

5.4.3 Erosion Control

Once slopes are stabilized the best long term erosion control measure is a permanent plant cover. Meiman (1974) noted that even small increases in ground cover can result in significant reductions in erosion and runoff. In addition, sites often have "sensitive" or "threshold" amounts of ground cover. If ground cover is depleted below this amount, dramatic increases in runoff and erosion may result.

In general, where the vegetation cover is less than 50% there is a doubling of the erosion rate for each 5 degree increase in slope (Meeuwig 1971). Doubling the length of slope increases erosion by a factor of 1.5 to 3 times (Wischmeier and Smith 1978). For this reason slopes should, where possible, be contoured to produce moderate slope angles. Where this is not possible, it is recommended that slope length is reduced by constructing back sloped benches. The creation of terraces or benches at intervals of 15 m or less on outsloped overburden has been shown to drastically reduce runoff and consequent erosion (Curtis 1971).

Soil erosion can be reduced by minimizing the time that recontoured surfaces are left bare. This can be achieved by scheduling topsoil respreading, seedbed cultivations, and sowing or planting operations concurrently. Progressive reclamation will also reduce the amount of disturbed area at any given time.

5.4.4 Drainage for Erosion Control

Installation of drainage will have a strong influence on erosion. Gregg (1976) presented a list of options to control groundwater seepage from road cuts. Horizontal drilling and placing of perforated pipe in the mountain sides gathers underground water and concentrates it in one area, thus greatly reducing the risk of landslides. The cost of this procedure however, prohibits use on areas except where there is a high landslide risk.

Other methods for high altitude roadbank stabilization include the following (Gregg 1976; Tupa 1978):

1. Permanent wall construction to limit the extent of slope exposure;
2. Ditching above the cutslope to channel surface runoff away from the cutslope;
3. Waterbars on the cutslope to interrupt runoff;
4. Rock channels where runoff is concentrated;
5. Small rock drainage layers under soil to collect seepage;
6. Large rock placement to stabilize slopes; and,
7. Elimination of topsoil to reduce the slip plane effect when topsoil cannot adhere to the slopes.

5.4.4.1 Diversions. Design of diversions in the snowpack zone should take into consideration the possibility of ice blockage. Shading of the ditch may increase the chance of ice formation, therefore the downslope portion of the ditch should be unshaded to ensure maximum effectiveness.

For alpine areas the gradient may need to be greater than is usually recommended. Some scouring of the diversion may need to be tolerated and special provisions made for sediment trapping at the diversion outlet (Meiman 1974).

Gregg (1976) found that jute laid in the bottom of the diversion ditches reduced velocity of flows, prevented scouring of ditches, and trapped sediment. It was also found to prevent surface erosion on road fill slopes on the Vail Pass roadway.

Often the excess runoff from poorly vegetated areas results in gully erosion. Meiman (1974) suggested the use of rock check dams for gully stabilization on small headwater drainages. These are long-term and low maintenance structures well suited to freeze-thaw conditions in the alpine.

Temporary measures to control erosion before a vegetation cover is established may include: diversion ditches, hay check dams, sediment ponds, special mulches, and soil stabilizers (Tupa 1978).

5.4.4.2 Waterbars or contour trenches. Erosion control waterways which direct water across slopes can stop runoff from gaining the speed and volume necessary to produce serious soil erosion. Welin (1974) found that the usual design of a waterbar with a maximum downslope angle of 1° at the top and 3° at the bottom did not work well on ski trail slopes at Vail, Colorado. Straw mulch can dam the channel as can ice during spring melt. He found waterbars with a top slope of 2° and increasing to 6° to 9° at the bottom worked best. However, it was important to carefully select the discharge points and waterbars of this design should not be used on disturbed slopes wider than 100 m.

David Walker and Associates Ltd. (1981) found that well vegetated waterbars with slopes less than 4° do not drain fast enough for the volume of runoff from ski slopes during spring-melt or after heavy rain. Channels in excess of 8° are steep enough to cause soil erosion. He recommended that waterbars be constructed with the downslope angle at 6° with a maximum of 8° and a minimum of 4°. They should be located every 15 to 30 m on slopes greater than 12°.

Contour trenches are subject to breakage because of rodent damage, excessive settling, shrinkage cracks, and overtopping because of excessive accumulation of snow and ice. This may require provision for regular maintenance (Meiman 1974).

5.4.4.3 Contour furrowing. Meiman (1974) considered contour furrowing preferable to contour trenching on most high elevation levels because of reduced cost and less risk from failure. The installation of contour furrows on high elevation watersheds may be limited by steep slopes, rockiness, and access by mechanical equipment.

5.4.5 Mulches for Erosion Control

Mulches can protect soil from erosion by shielding it from raindrop impact, retarding water flow, trapping silt on-site, and increasing water penetration. Properly anchored mulches may also reduce wind velocity.

Kay (1978) provided a general review of the effectiveness and limitations of various mulches for erosion control and seedling establishment. These included organic mulches (straw, hay, wood-cellulose fibres applied by hydromulching, and wood residues such as wood chips and bark), fabric or mats, soil, and rock. A summary of his findings are given in Table 8. Kay noted that straw and hay provide the best results in both protection and encouragement of plant growth, if weeds or fire hazards are not a problem. Hydraulic mulching offers a weed-free mulch of low fire hazard, but is not always as effective as straw. Wood residues such as bark or wood chips are less effective than straw and may discourage plant growth if applied at excessive rates. Kay’s work was not specifically designed for the alpine environment therefore care should be taken in extrapolating his results.

Mulches of crushed stone or gravel 2.5 cm deep were found to provide more effective erosion control than 4480 kg/ha of straw in trials in Nevada and California (Meyer et al. 1972). Kay (1978) also found a ground cover of gravel to be effective in reducing wind and water erosion and encouraging invasion by indigenous plant species. Stone and gravel mulches may be effective on ridge tops or exposed slopes that are particularly susceptible to wind erosion.

Thomson and Sembenelli (1987) tested jute mesh for erosion control at 1995 m A.S.L. in the western Italian Alps. The test site was located on actively eroded 27° south-facing slopes. Soils are silty sands with shaly stones. The jute mesh had voids measuring 11 X 14 mm with 4 mm diameter yarns. The seed mix was applied over the net and without fertilizer.

Table 8. Summary of methods of common erosion-control practices. A rating of 1 is minimal while a rating of 10 is excellent.

	Treatment	Comments	Pregermination erosion effectiveness	Effectiveness on plant establishment
1.	Seed and fertilizer broadcast on the surface, no soil coverage or mulch.	Inexpensive and fast. Most effective on rough seedbeds with minimum slope and erodability where seed will cover naturally with soil. Suitable for remote or critical areas where machinery cannot be taken.	1	1-4
2.	Hydroseeding or hydromulching (seed + fertilizer) with 500 lb wood fibre, 1500 gal water/3 acres.	Similar effectiveness to broadcasting seed and fertilizer. Not enough fibre to hold seed in place or produce a mulch effect. Seed distribution would be improved by increased volume of water	1	1-4
3.	Seed and fertilizer broadcast and covered with soil (raking or dragging a chain, etc.)	Does not require special equipment. Generally a very effective treatment. Labour cost is high on areas not accessible by equipment.	1	3-4
4.	Hydromulching with 1500 lb/acre wood fibre (plus seed and fertilizer).	Most common hydromulch mix in California. Advantages include holding seed and fertilizer in place on steep and smooth slopes where there may not be an alternative method. Only a minimal mulch effect. Cost is much higher than 2.	2	3-5
5.	Hydromulching with 1500 lb wood fibre plus an organic glue: Ecology Control, Terratack III etc., plus seed and fertilizer.	The addition of an organic glue will sometimes improve fibre holding and germination. Does not increase labour or machinery cost.	2+	3-6
6.	Hydromulching with 2000 to 3000 lb/acre wood fibre plus seed and fertilizer.	Produces a true mulch effect and some erosion protection. Commonly better results than 1,000 lb fibre or fibre plus glue.	2-3	4-7
7.	Seed and fertilizer broadcast and covered with soil as in 3 above, but followed with hydromulch of wood fibre at 2000 to 3000 lb/acre.	Very effective, combines advantages of seed coverage and mulching.	2-3	6-8

Continued...

Table 8. Concluded.

	Treatment	Comments	Pregermination erosion effectiveness	Effectiveness on plant establishment
8.	Straw or hay broadcast with straw blower on the surface at 3000 lb/acre and tacked down (asphalt emulsion, Terratack II, etc.). Seed and fertilizer broadcast with hydroseeder or by hand.	Very effective as energy absorber; mulch and straw forms small dams to hold some soil. May be weedy depending on straw source. Not for cut slopes steeper than 2:1. Cost would increase significantly if slopes over 50 feet from access, or application is uphill. Wind is common limitation in application.	5-7	8-10
9.	Straw broadcast 4000 lb/acre and rolled to incorporate (punched), another 4000 lb straw broadcast and rolled, seeded and fertilized. Seed and fertilizer broadcast with hydroseeder or by hand.	Common on difficult fill slopes. Very effective. Not possible on most cut slopes. Very weedy. Cost would increase significantly if slopes over 50 feet from access.	6-8	8-10
10.	Roll-out mats (jute, excelsior, etc.). Held in place with wire staples. Seed and fertilizer as in 1 or 2.	Some are a good mulch, weed free, adapted to small areas. Can be installed any season, cuts or fills. Unsightly. Difficult to install on rocky soils. Expensive to install and costly.	5-7	5-10
11.	Polyethylene sheets (4 mil), seed and fertilizer as in 1 or 2, use clear plastic, black if no seed is used.	Useful for temporary control. Can be installed any season. Unsightly, wind is a problem in installation and maintenance. May be difficult to establish plants.	10	?
12.	Seed and fertilizer broadcast, or hydromulched with fibre (treatment 2 or 4), followed by erosion control chemical such as polyvinyl acetate at 6:1 dilution (6 parts water) at 1000 lb solid/acre (approx. 200 gal. PVA).	Very expensive, but will hold soil and seed in some very difficult conditions. May restrict penetration of water into soil. Will not cure below 55°F. Not effective on soils which crack. Will not support animal or vehicle traffic. May be effective with transplanted shrubs.	10	?

Source: Kay (1978).

Monitoring of the erosion process consisted of measuring suspended sediment loads in runoff water, downslope movement of coarse soil particles, and changes in the slope profile. Assessments were made in November 1985 (at time of installation), June 1986, and October 1986. Over the monitoring period the amount of fines carried in runoff water from the jute section was only 10% of the control values. There was also a substantial reduction in the movement of coarse soil particles. Profile measurements revealed a loss of 0.5 mm depth from the jute section compared to the 6 mm lost from unprotected sections. The authors considered that the jute mesh created mini reservoirs which encouraged the deposition of suspended sediments. It also provided protection of the soil surface against ice, snow, animals, and rolling debris.

It is important that mulches are installed in a manner that resists running water. Straw and light weight materials work best when crimped into the soil. Erosion controlling mats may allow erosion to occur beneath them if they are not secured tightly to the soil surface. This is especially critical during snowmelt where a steady flow of water may last several weeks. Finally, mulching materials should be compatible with the drainage system to prevent clogging of culverts, diversions or drop inlet structures (Meiman 1974).

5.4.6 Equipment

Mountain climbing backhoes introduced to the United States market from Europe are reported to be capable of operating on steep (20° to 45°) slopes, and on rough terrain (McDermott et al. 1984). Legs and wheels on these machines can be raised, lowered, extended, retracted, or widened as required, through use of individual controls. This provides maneuverability, stability, and steep-slope safety. All mountain-climbing backhoes are fully hydraulic and have four legs (two outriggers with pods, and two with balloon tires). Tested machines showed good performance in construction of water drainage channels, cleaning culverts, slope stabilization, road maintenance, and other engineering work. The machines were also reported as causing minimal environmental impact relative to other heavy equipment. Adolphson et al. (1982) reported that a similar machine was developed at the San Dimas Equipment Development Centre in California. Limited tests have been conducted on this machine.

Basins or depressions that trap runoff, snow, and blowing topsoil as well as reducing wind erosion may be constructed with the use of a basin blade. This is a large crescent-shaped steel blade mounted on the rear of a crawler tractor. The tractor is driven along the slope and the blade is periodically raised and lowered. The depressions provide the advantages of terracing (reduced erosion and increased infiltration) with fewer hazards and less expense (Hallman 1982). The blade is 3 m wide and can create 91 cm deep depressions.

5.5 SURFACE PREPARATION

Surface preparation involves measures to provide the best seedbed possible for revegetation. In the alpine, these measures must address certain soil processes which limit plant establishment. Downslope flow of saturated soil (solifluction) or downslope displacement of soil as a result of alternate freezing and thawing (frost creep) can cause significant disturbance to soils. Wind erosion may also prevent vegetation becoming established on exposed upper slopes and ridges. Alpine soils may also be coarse-textured with high coarse fragment contents, and therefore, have low moisture holding capability.

5.5.1 Grading

Grading spoil to create a smooth surface is not recommended because:

1. It may result in excessive soil compaction with a consequent increased rate of runoff, reduced soil moisture, and increased soil erosion;
2. A smooth seedbed does not provide sheltered microsites for seed germination and establishment. This is particularly important in an alpine environment where high winds may blow seeds away and high surface temperatures during the growing season may kill seedlings (Hubbard and Bell 1977); and,
3. Smoothly bladed slopes with a thick layer of topsoil may slide when the soil becomes saturated. When cut slopes are constructed they should, therefore, be left rough. If they are smooth, the topsoil should be bonded to the subsoil by loosening the subsoil before the topsoil is applied. Slopes near the

angle of repose should then be mechanically packed to make them firm and stable (Nishimura 1974).

A rough ripped surface allows moisture to infiltrate into the soil and provides greater stability. This can be most effectively undertaken as the slope is being constructed rather than roughening the surface in a subsequent operation (Brammer 1978).

5.5.2 Use of Topsoil

On alpine disturbances, availability of water during the growing season is one of the most limiting environmental factors to the survival of first year seedlings. On Beartooth Plateau in southern Montana, seedling mortality resulted more from severe drought in the upper 15 cm of soil than from infertility or soil chemical toxicity (Brown et al. 1976). Severe water stress was commonly experienced by plants growing on mine spoil material but not those growing on undisturbed tundra (as determined by simultaneous measurements of leaf and soil water potentials). This was attributed, in part, to the lower water holding capacity near the surface of the rocky mine spoil materials. They found that topsoil amended spoil produced better plant growth than raw spoil.

Soil provides a better seedbed than raw spoil, because of the better structure, nutrient availability, and soil biotic component. In some situations, soil may also have a lighter colour (higher albedo) than the spoil (e.g., carbonaceous material) and therefore, does not reach the very high temperatures which may be lethal to seedlings (Hubbard and Bell 1977).

Greller (1974) suggested that addition of topsoil may help revegetation of road fill slopes in the alpine. However, he noted that the benefits of improved surface stability and soil fertility may be offset by higher soil temperatures in summer, and by needle-ice activity in spring and autumn which would adversely affect seedling survival.

Topsoil replacement has been used as part of hiking trail rehabilitation on areas where soil erosion was severe (Walker and Harrison 1986). Introduction of exotic species was a concern so a commercial potting soil was used. This had been sterilized to kill weed seeds and was packaged in 20 kg plastic bags. The bags of soil were easy to handle and could be transported

by helicopter to inaccessible areas, where they could be stockpiled on-site until required.

Berg and Barrau (1978) reported that topsoiling, although expensive, can reduce the need for maintenance fertilization on coarse spoil material in the subalpine. They cited several soil survey reports from subalpine areas in Colorado which indicated that based on the analysis of the soil-sized fraction:

Of the total nitrogen in the 60 cm soil profiles:

1/3 of the N was in the surface 7.6 cm
1/2 of the N was in the surface 15.2 cm
and, 3/4 of the N was in the surface 30.5 cm.

These figures did not include N in litter and humus. They estimated that conservation and replacement of the organic horizons and the top 15 cm of soil will result in replacing an average of about 1681 kg N/ha. However, because of the wide C:N ratio, the amount of N available to seedlings was limited.

5.5.3 Topsoil Quality

Alpine soils are extremely variable even over short distances. They vary greatly in depth, fertility, and susceptibility to erosion, although they tend to be shallow, poorly developed, and have high coarse fragment content. The depth of the A horizon tends to be greatest on minimal snow cover, early melting snowbank and wet meadow sites (Burns 1980). Because of the thin Ah horizons, topsoil salvage in alpine areas may include removal of the A, B, and probably part of the C horizon.

The selection of soil suitable for salvage would need to consider those factors that limit plant establishment and growth in the alpine. Needle-ice and solifluction are hazards in establishing alpine plants. High solar radiation loads and high winds also mean that soils may become droughty during the growing season. Selection of soils for salvage needs to consider soil properties which:

1. Provide adequate moisture holding capacity during the growing season;
2. Provide good drainage;
3. Provide adequate nutrient holding capability; and,

4. Limit the incidence of needle-ice.

Brink et al. (1967) investigated the influence of needle-ice on seedling establishment in southwestern British Columbia. Needle-ice development was highest on a "muck soil", followed next by a sandy loam soil, and least on a clay loam. Dense seedling stands tended to alter the microclimate at the soil surface and reduce or prevent needle-ice development and seedling root damage. Needle-ice tended to develop on non-vegetated patches. The needle-ice layers developing on compacted soil are firmer, denser, and thinner and contained relatively more water than ice developing on friable soil.

Brown (1984) considered that the greatest asset of topsoil for alpine reclamation is its texture and the associated moisture holding capability. He suggested that the organic and nutrient constituents of a growth medium could be easily and economically provided by amendment with organics and fertilizers.

Nishimura (1974) stated that a quality topsoil should have a minimum plant available moisture capacity of 7% (by weight). Organic matter should be in the range of 1% to 20%. A clay content of 30% to 35% should be the maximum.

5.5.4 Topsoil Depth

Macyk (1979) measured forage production on areas of reclaimed mine spoil which had received different depths of soil cover. The study area was located near Grande Cache at 1035 m A.S.L. Vegetation in the area is characteristic of the lower Foothills Section of the Boreal Forest Region. Twenty six grass samples were taken from areas that were under similar management during the previous 5 years. The greatest yields occurred in areas having a soil cover of 25 to 35 cm (the greatest measured) and the lowest yields in areas having a soil cover less than 5 cm. Macyk concluded that 10 to 15 cm should be the absolute minimum soil replacement depth and that 15 to 20 cm would be more desirable. Vegetation established in areas having less than 5 cm of soil, but the cover produced was not adequate to prevent even minor erosion. In practice, the amount of soil available and the efficiency of salvage will dictate the amount used as top dressing.

Topsoil was placed on all slopes of the Vail Pass roadway project between Copper Mountain and Vail, Colorado. Elevations of the roadway range from 2560 m A.S.L. to 3200 m A.S.L. Contractors were required to place a minimum of 10 cm of topsoil on all the disturbed slopes (Gregg 1976).

Nishimura (1974) recommended that topsoil should be spread 10 to 15 cm over subsoil areas and coarse-textured materials exposed by construction. It was not considered practical to spread topsoil less than 5 cm thick unless the area was relatively level and the underlying material had enough fines to aid grass establishment. Placing topsoil more than 15 cm deep on a slope may increase the probability of the topsoil slumping down the slope.

Where topsoil is in limited supply, it may be spread in "islands" to provide some sites with optimum depths, and other areas with no topsoil, rather than spreading it in a thin lift over the entire site. Selection of the appropriate sites for these islands will depend on the reclamation concerns at the site: placing the topsoil on "easy-to-reclaim" sites will help guarantee success; placing it on more critical areas (e.g., south aspects) will increase the likelihood of success on those sites.

5.5.5 Seedbed Preparation

The soil surface should be loosened by ripping, rototilling, harrowing, or raking to facilitate intimate contact between the seed and soil, and to improve the aeration and hydraulic conductivity (Brown et al. 1976). Growth conditions are more favourable on a harrowed surface than one that has only been graded. However, harrowing may increase the incidence of needle-ice (Hubbard and Bell 1977). Ideally, the soil should be tilled 15 to 20 cm deep and the top 10 cm pulverized into small aggregates. In the mountains, the steep topography will probably limit the seedbed to be broken to only 10 to 15 cm, presumably due to equipment limitations (Nishimura 1974).

5.5.6 Microsite Manipulation

In alpine environments plants are small, close to the ground, and often widely separated by bare soil or rock. The modification of microclimate by vegetation is minimal and the physical environment dominates the vegetation. In such open and windy places, the effects of microenvironment are pro-

nounced. The microtopographic effect may be caused by a ridge, a rock, or by another plant itself.

Boulders, rock outcrops, and patches of krumholz produce small elongated snowdrifts in the lee. Small depressions also catch blowing snow. Miniature snow drifts create microtopographic gradients with species that need protection from snow interspersed with those that do not (Billings 1978).

On steep slopes the creation of benches, serrations, or rough grading can create microsites favourable to plant establishment. A roughened surface can be achieved by eliminating the final grading operation or track walking (walking a bulldozer up and down a slope to create kleat marks) (Kay 1978).

A large scale reclamation program to reclaim two large tailings areas (total area about 50 ha) was undertaken at the abandoned Urad mine located at 3120 m A.S.L., about 80 km west of Denver, Colorado (Hassell 1982). Part of the reclamation process included covering the tailings areas with waste rock to a depth of 1 m on the level surfaces and 3 m on the dam faces to form a drain blanket. Small hills were also constructed to modify the flat contour and to provide windbreaks. Hassell (1982) considered that the rock eliminated wind and water erosion of the tailings. The dark waste rock absorbed heat from the sun and maintained a higher surface temperature which increased the length of the growing day. He also suggested that the rock acted as a mulch and reduced water loss by evaporation from the tailings.

5.5.7 Equipment

Agricultural type harrows may not withstand the rocky soils encountered in alpine areas. Walker (1981) reported use of a custom made harrow at Lake Louise Ski Area. Heavy metal teeth were welded onto several 50 cm pieces of 10 to 15 cm diameter pipe. This heavy duty set of harrows was pulled behind a Ferret all-terrain vehicle. Very steep slopes were scarified manually using garden rakes and pick axes.

On high elevation road cut and fill slopes in Colorado, topsoil was spread by pushing the soil up on cut slopes using a dozer or by a drag line spreading topsoil on the fill slopes (Gregg 1976). Gregg noted that if the topsoil was not ‘keyed’ into the underlying material then there was a risk of slip planing especially if the soil was saturated.

The U.S. Forest Service investigated the concept of providing support to equipment working on steep slopes through use of a self-contained tether cable system (McKenzie and Richardson 1975). The purpose of the tether cable system was to anchor a vehicle on slopes so as to reduce its weight component to near zero. This allows the vehicle to operate on steep slopes without causing excessive terrain damage. Vehicles equipped with a self-contained tether cable system should have the force of the tether acting through the vehicle's centre of gravity to eliminate tipping. A swivel-arm pivots from the vehicle's centre of gravity allowing the vehicle to turn full circle around its tether. Recommended tether anchor points included; rocks using rock bolts, and deadman or earth anchors.

The vehicle could be a diesel-powered two-track, articulated four-track, or articulated rubber-tired vehicle. Of these three it was suggested that the articulated rubber-tired vehicle may be the best choice since it caused the least terrain damage.

A Hodder gouger that creates numerous small depressions may be useful for alpine reclamation. It provides a suitable microclimate for plant establishment by increasing moisture availability, preventing wind and water erosion, and providing shade (Hallman 1982). The Hodder gouger is operated hydraulically and towed behind a tractor. Depression depths, cycle rates, and blade configuration can be varied to suit site conditions. Spring-loaded blade arms enable operation on rocky sites. The Hodder gouger is 3.4 m wide, and the range of depression widths and lengths are 38 to 56 cm and 0.9 to 1.2 m, respectively.

5.6 REVEGETATION

5.6.1 Plant Succession

Selection of suitable plant materials is critical for successful revegetation. One of the most productive methods of identifying adapted species for revegetation of alpine disturbances is to examine natural successional processes on old local disturbances such as road cuts and fills, and gravel pits (Brown and Johnston 1980b; Chambers et al. 1984, 1988). This provides a list of colonizer species from which adapted species and ecotypes suitable for reclamation can be selected (Brown et al. 1976).

Plant colonization of disturbed sites on the Beartooth Plateau in southern Montana was found to be highly site dependant. The rate of colonization was primarily influenced by: availability of soil water, soil chemistry conditions, and time since disturbance.

Topography and soil structure may also be important in some areas. Of nearly 200 alpine vascular plant species comprising the flora of the Beartooth Plateau (Johnson and Billings 1962) only about 10% were active colonizers of disturbances. Fewer than half of these were found on virtually all disturbances of more than a few years of age. These species included: *Deschampsia caespitosa*, *Carex* sp., *Poa alpina*, *Trisetum spicatum*, *Agropyron scribneri*, and *Phleum alpinum*.

A few species of forbs were noted as colonizers but only on more mesic sites with pH values above five. These included *Lupinus* sp., *Antennaria alpina*, *Sibbaldia procumbens*, and in a few locations *Epilobium alpinum* and *Senecio* spp. (Brown et al. 1976).

In alpine succession, early colonizing species are also members of the climax community (Chambers et al. 1988). However, distinct seral stages do exist on most disturbed alpine sites (Bliss 1962). Chambers et al. (1984) have classified alpine plant species according to their frequency of occurrence in different successional stages.

Four unreclaimed alpine disturbed sites in the Beartooth Mountains of Montana were examined to identify the early colonizer species. The four study sites selected had been disturbed 20 to 30 years previously, and represented a range in elevation, disturbance type, and geologic material. Soils on all sites were acid, ranging in pH from 2.5 to 6.5. Species that occurred in relatively high abundance on three or four sites were classified as early seral dominants. These included *Carex paysonis*, *Deschampsia caespitosa*, *Sibbaldia procumbens*, *Trisetum spicatum*, *Polygonum bistortoides* and *Potentilla diversifolia*.

Late seral dominants are those species that comprise a major component of late successional ecosystems but that also occur as colonizing species on disturbed sites. They are most often colonizers on sites that have favourable soil characteristics and are close to the seed source. Examples of late seral dominant species are *Geum rossii* and *Artemisia scopulorum*. The

third category are those species that are only occasionally found as colonizers and were classified as rare.

Deschampsia caespitosa was considered an exception to the classification system in that it can occur as either an early or late seral dominant. On ridges and open fell-fields, few species can survive and there is no species replacement over time. Species found on these sites are therefore, also exceptions to the classification system.

Initial colonizers of disturbed sites often exhibit broad ecological amplitudes and are usually widely distributed. They often have large and consistent seed production capabilities, effective seed dispersal mechanisms, high seed longevity, and high rate of growth and development. They may also be able to tolerate high concentrations of heavy metals, low pH, and other adverse disturbance conditions. For example, frequent colonizers such as *Deschampsia caespitosa* typically produce large quantities of small seeds with high seed longevity, high seed dispersal capability, high plant growth rates, and low root to plant biomass ratios (Chambers et al. 1984).

Late seral species often have slower growth rates, lower seed production and longevity, and lower rates of seed dispersal than early seral species. For example, species typical of late seral communities such as *Geum rossii*, produce small quantities of larger sized seeds with relatively short seed longevity, low seed dispersal capability, low growth rates, and high root to plant biomass ratio. In addition, *Deschampsia caespitosa* tends to have a shallower, less extensive root system and higher nutrient requirements than *Geum rossii* (Chambers et al. 1987a).

Fox (1981) studied the relationship between soil frost disturbance and diversity of vascular plant species in arctic-alpine fell-field vegetation in the White Mountains (950 to 1100 m A.S.L.) of interior Alaska. The study sites were located on windswept ridges or slopes (fell-fields) with little or no permanent snow cover. The vegetation cover is discontinuous and dominated by *Dryas octopetala*, *Diapensia lapponica*, and *Salix phlebophylla*, and *fruticose lichens*. A stony pavement is found between the vegetation patches. In addition, there are discontinuous frost scars (0.2 to 1.0 m across) caused by freeze-thaw of soil and frost-heaving of some plants.

In the highly frost disturbed areas, Fox noted that *Arenarius oxytropis*, *Campanula* and *Antennaria* were frequent, in comparison to their low frequency in relatively undisturbed areas. He found that species diversity was at a maximum at intermediate levels of disturbance, because of increased evenness of relative abundances, but not necessarily increased number of species. He noted that because soil frost disturbance is frequent in alpine tundras, these disturbances could be an important factor in species diversity differences between tundra vegetation types.

Bell and Bliss (1973) studied plant invasion at several alpine and subalpine sites on road cuts 31 years after a road was constructed in Olympic National Park, Washington. The road cut resulted in three different habitats, with different species composition and cover: the cut itself, the fill below the road, and an area at the base of the fill where the substrate is stable. The road cuts within the alpine showed little evidence of plant invasion whereas those within subalpine meadows had much greater cover establishment, especially at lower elevations.

Road cuts in bedrock remained essentially bare, while cuts made in scree had a cover of 16.1% (Table 9). This cover primarily resulted from small pieces of turf which have eroded from the upper edges of cuts. These turf pieces initiated plant establishment. *Phlox diffusa* var. *longistylis* and *Calamagrostis purpurascens* were most frequent in old turf, while *Achillea millefolium* ssp. *lanulosa* var. *alpicola*, or *Phacelia sericea* comprised the newly-established plants. The base of the fill had a dense cover (96.0%) developed under the favourable conditions of a stable substrate, deeper and late-melting snow, and plentiful runoff from the road and slope above.

Greller (1974) studied plant succession on road fill slopes in the alpine tundra of Rocky Mountain National Park, Colorado. The fill slopes had gradients of usually 27° (50%) or more. Vegetation cover was examined at eight, 10 metre transects on two roads that had been constructed 40 to 50 years previously.

Plant coverage on the fill slopes was only half that of natural undisturbed stands. The mosaic of pioneer vegetation types appeared to be correlated with site factors: altitude, exposure, substrate texture, and degree of slope. North-facing slopes (and those with some late-snow cover) were dominated by *Poa fendleriana* while south-facing slopes tended to be

Table 9. Plant cover (percent) of selected species for alpine habitats in relation to road cuts, Olympic National Park in 1969.

Species	Undisturbed Tundra	Road cut Scree	Road cut Rock	Road Fill	Base of Fill
Juniperus communis var. *montana*	0	0	0	0	9.3
Festuca idahoensis	10.8	0.4	0	0	12.5
Poa cusickii var. *epilis*	0.2	0.1	0	0	7.8
Phlox diffusa var. *longistylis*	21.5	2.8	0	0	18.8
Phacelia sericea	0	2.3	0	1.8	2.5
Achillea millefolium ssp. *lanulosa* var. *alpicola*	0.6	3.7	0.9	0	36.1
Mosses	2.8	0.5	0	0	0
Lichens	7.3	0.2	0	0	0
TOTAL PLANT COVER	65.7	16.1	3.3	2.2	96.0
Exposed soil and rock	26.7	83.2	96.7	98.8	4.0
Leaf Litter	8.2	0.7	0	0	0

Source: Bell and Bliss (1973)

dominated by *Agropyron scribneri*. *Trifolium dasyphyllum* tended to dominate flat sites. *Geum rossii*, *Mertensia viridis*, *Polygonum bistortoides*, and *Polemonium viscosum* were most prominent on the outwash and the flat upper edges of the lower slopes. Road cuts tended to have greater plant diversity than fill slopes. Greller attributed the difference to a greater variety of microhabitats present on the cuts because of strike and dip of the rock outcrops, rates of rock weathering, and presence of seepage. The fill slopes tended to be more uniform because of vertical sorting of materials (fine grained material at top of slope, rocks at base). The main factor limiting colonization was stability of the slopes. *Poa arctica* was notable in being present on extremely unstable slopes. The bunch grasses *Agropyron scribneri*, *Poa fendleriana*, *Trisetum spicatum* and *Poa glauca* were considered important pioneer species for stabilizing the slopes. Increased soil moisture and organic matter tended to facilitate increased plant colonization.

Polster (1975) studied the vegetation on limestone talus slopes on the Liard Plateau in northern B.C., including species which colonize and stabilize these areas. *Dryas integrifolia* and other mat forming species were the initial colonizers of unstable areas. At slope bottoms, where large particle size results in moisture being the limiting factor for vegetation, xeric species, including *Saxifraga tricuspidata*, *Carex scirpoidea*, and *Cystopteris fragilis* were the first to establish. Unstable north-facing slopes were found to be colonized by *Salix polaris*, *Salix lanata*, and *Salix alexensis*. These species have extensive root systems. Also found on these sites were *Poa alpina*, *Cerastium beeringianum*, and *Melandrium apetalum*. Other species found on most portions of both north and south-facing slopes were *Polygonum viviparum*, *Silene acaulis*, *Salix glauca*, and *Trisetum spicatum*.

Several studies in tundra communities in Alaska have shown that the majority of buried seed banks are moderately large and are important in colonizing disturbances (Gartner et al. 1983). Ebersole (1989) found that in contrast to temperate seed banks, which often contain early successional species no longer present in the vegetation, seed bank taxa at an Alaskan Arctic Coastal Plain site occurred within a short distance of the sample sites because of long persistence of the communities. Of the common colonizers on a nearby 30 year old disturbance, *Betula nana*, *Poa arctica*, *Salix* spp., and *Arctagrostis latifolia* were absent or present in only small amounts in the seed bank and apparently colonized mainly from seeds dispersed following disturbance. However, *Eriophorum angustifolium*, another common colonizer, was present in the seed bank of wet areas, and *Carex bigelowii* and *C. aquatilis* were abundant in the seed bank of several communities. Germination from the seed bank was an important means of colonizing disturbances for these taxa.

Kershaw and Kershaw (1987) investigated natural plant colonizers on abandoned borrow pits within the Dempster Highway and CANOC Project corridors in northwestern Canada. Sites were located in a wide range of habitats (from latitude 63° 18' to 67° 15') and elevation range (425 to 1710 m A.S.L.), within the Selwyn, Mackenzie, Ogilvie and Richardson Mountains. The borrow pits were considered to have mineral substrates that are coarser, drier, and therefore, warmer than those of the surrounding undisturbed areas.

Of the 433 taxa recorded from the 80 borrow pits surveyed, 18 had colonized pits in all four geographic regions: *Arctagrostis latifolia*, *Betula*

glandulosa, *Empetrum nigrum*, *Epilobium angustifolium*, *E. latifolium*, *Equisetum arvense*, *Hedysarum alpinum*, *Poa arctica*, *P. glauca*, *Populus balsamifera*, *Salix alaxensis*, *S. glauca*, *S. planifolia*, *Vaccinium uliginosum*, *Cetraria cucullata*, *Polytrichum commune*, *P. juniperinum*, and *P. piliferum*.

Forty nine vascular and 18 non-vascular plant species have been identified as successful colonizers (Table 10). The authors considered these species as suitable for use in revegetation of disturbed tundra in northwestern Canada.

Secondary succession on alpine tundra that had been trampled in Rocky Mountain National Park in Colorado was found to be very slow (Willard and Marr 1971). However, some species were noted to invade areas of bare soils. These included *Minutia rubella*, *Draba crassifolia*, *D. nivalis*, *Stellaria umbellata*, *Artemisia scopulorum*, *Mertensia viridis*, *Sedum lanceolatum*, and *Bistorta bistortoides*.

They also noted that four plants: *Matricaria matricarioides*, *Chenopodium album*, *Capsella bursa-pastoris*, and *Erigeron peregrinus* also appeared on the disturbed areas. These were the first individuals of these species to be found anywhere on Trial Ridge during the 5 years of the study.

Wheeler and Sawyer (1982) developed a list of species recommended for use in revegetation in the alpine in Montana based on identification of locally abundant colonizers (Table 11). An examination of exploration trenches seeded to three exotic grasses and one clover over a 5 year period indicated that the initially high cover and vigour of the seeded species declined and native species from the surrounding areas began to invade the reclaimed areas. The trenches were located in the Beartooth Mountains of Montana at elevations ranging from 2500 m to 2835 m A.S.L. They found a definite correlation between the colonizing species and the surrounding habitat type. There was some variation in colonization among the alpine and two tree line habitat types (*Pinus albicaulis* and *Pinus albicaulis - Abies lasiocarpa*) but this was slight compared to the difference between the subalpine (*Abies lasiocarpa - Pinus albicaulis/Vaccinium scoparium*) and the other habitat types. The timberline habitats tended to have an understorey similar to that of the nearby alpine vegetation.

Table 10. Plant species with demonstrated potential for revegetation programmes in continental tundra regions of northwestern Canada.

Vascular plants	
Androsace chamaejasme	*Hedysarum alpinum*
Anemone parviflora	*Juncus casteneus*
Arctagrositis latifolia	*Lloydia serotina*
Arctostaphylos alpina	*Minuartia rossii elegans*
Arnica alpinus	*Pedicularis lanata*
Astragalus alpinus	*Poa arctica*
Betula glandulosa	*P. glauca*
Carex aquatilis	*Populus balsamifera*
C. atrosquama	*Potentilla bilfora*
C. bigelowii	*Salix alaxensis*
C. lugens	*S. arctica x polaris*
C. membranacea	*S. dodgeana*
C. nardina	*S. glauca*
C. physodes	*S. lanata*
C. praticola	*S. planifolia*
C. scirpoidea	*Saxifraga aizoides*
Dryas integrifolia	*S. oppositifolia*
Empetrum nigrum	*S. tricuspidata*
Epilobium angustifolium	*Sibbaldia procumbens*
E. latifolium	*Silene acaulis*
Equisetum arvense	*Thalictrum alpinum*
Erigeron acris	*Vaccinium uliginosum*
Eriophorum angustifolium	*V. vitis-idaea*
E. scheuchzeri	
Erysimum pallisii	
Festuca altica	
Non-vascular plants	
Lichens	
Baeomyces roseus	*Lecidea auriculata*
Cetraria cucullata	*Nephroma expallidum*
Cladonia cornuta	*Peltigera canina*
C. pocillum	*Stereocaulon alpinum*
C. subulata	*Toninia lobulata*
Lecanora flavida	*Verrucaria aethiobola*
Mosses	
Ceratadon purpureus	*Polytrichum piliferum*
Polytrichum commune	*P. strictum*
P. juniperinum	*Tomenthyphum nitens*

Source: Kershaw and Kershaw (1987).

Table 11. Species recommended for revegetating the Benbow trenches based on high frequency and cover-abundance values for colonizers.

<u>Grasses</u>

Agrositanion saxicola
Calamagrostis purpurascens
Poa interior

<u>Herbs</u>

Antennaria umbrinella
Campanula rotundifolia
Geum rossii
Lupinus leucophyllus
Polygonum bistortoides
Senecio canus
Solidago multiradiata

<u>Shrubs</u>

Artemisia campestris spp. *borealis*
Potentilla fruticosa

Source: Wheeler and Sawyer (1982)

Brown and Johnston (1979, 1980b) found that introduced species such as *Bromus inermus* (smooth brome) and *Agropyron intermedium* (intermediate wheatgrass) were no longer present 4 years after planting on a subalpine - alpine site that had been mined in southwestern Montana. However, native adapted species from the area such as *Deschampsia caespitosa* (tufted hair-grass) increased in density, cover, and biomass production over the same period.

5.6.2 <u>Native Species Tested in Revegetation Trials</u>

In spite of the great progress made by high altitude revegetation research in North America, documented studies on revegetation above timberline are still rather few (Urbanska and Schutz 1986).

Native species have some advantages compared to agronomic species in the alpine. In general, native species are more tolerant of low fertility, soil acidity, short growing seasons, and other site factors characteristic of high elevations. Introduced species tend to have better seedling vigour and produce early vigorous growth. However, they require more nutrients to maintain adequate stands (Carlson 1986).

Harrington (1946) undertook one of the earliest reported revegetation trials in the alpine. Road cuts with exposures of bare rock and soil at 2743 to 3353 m A.S.L. in Rocky Mountain National Park, Colorado were seeded with many native species. Seed was gathered from the lower limits of the altitudinal range of each species and was sown in September and October, 1938. Seed was scratched in by hoe or scattered on the surface. Some plants of *Phacelia sericea* were transplanted at sites 3414 m A.S.L. Observations were carried out in 1944 and 1945. He found that seeding of denuded areas at high elevations with the seed of certain native species did help in initiating natural succession. Several species showed promise: *Thermopsis divaricarpa*, *Phacelia sericea*, *Phacelia heterophylla*, *Agrostis scabra*, *Deschampsia caespitosa*, *Bromus ciliatus*, *Heracleum lanatum*, *Trisetum spicatum*, *Jamesia americana*, *Poa alpina*, *Cryptantha* sp., *Achillea millefolium*, *Rubus idaeus*, *Artemisia norvegica* ssp. *saxatilis*, and *Penstemon whippleanus*.

Several native grass species were tested on a large scale reclamation trial at the McLaren Mine in the Beartooth Mountains, Montana (2956 m A.S.L.) (Brown and Johnston 1978). This mine is located in the transition zone between subalpine and alpine ecosystems. The acid mine spoil was limed, fertilized, and manured.

The plot was also covered with a surface mulch consisting of 2500 kg/ha of straw, tacked down with water soluble asphalt emulsion. First year results are presented in Table 12. *Triticum aestivum* apparently became established from seed incorporated in the straw mulch. Four native species provided virtually all of the first year cover and production on the site (*Deschampsia caespitosa*, *Poa alpina*, *Agropyron trachycaulum*, and *Phleum alpinum*). These species have been previously noted to be active colonizers on disturbed sites throughout the Beartooth Plateau. The authors noted that some of the other species planted may have delayed germination and may contribute to cover in future years.

Table 12. Summary of first year results of seeded demonstration area on McLaren Mine, Beartooth Plateau, Montana.

Species	1976 Seeding rate kg/ha	1977 No. plants per m^2	1977 Plant Frequency
Agropyron scribneri	1.6	0	0
A. trachycaulum	8.6	26	0.83
Carex drummondii	7.8	0	0
Deschampsia caespitosa	45.2	279	1.00
Phleum alpinum	5.2	14	0.43
Poa alpina	12.7	72	0.85
Trisetum spicatum	1.9	0	0
Triticum aestivum	0	4	0.19
weeds	0	4	0.39
Total	83.0	399	
Average production		133 kg/ha	
Total cover		71.0 percent	
Average plant cover		21.7 percent	
Average litter cover (including mulch)		49.3 percent	

Source: Brown and Johnston (1978)

Guillaume et al. (1986) tested native species seeded as monocultures in topsoil and as a mixture in subsoil or rock waste at the Climax Mine, Colorado. Introduced species were also seeded as monocultures in topsoil. Topsoil and subsoil sites were located on a west-facing 3° slope at an elevation of 3630 m (about 130 m above tree line). These sites normally have continuous snow cover during the winter. About 15 cm of topsoil was removed from three 9 m by 90 m blocks to expose the subsoil site and placed on two 6 m by 90 m blocks to make the topsoil site. Coarse fragment content was 15% in the topsoil and 20% in the subsoil. Organic matter content was 3.6% in topsoil and 1.3% in subsoil.

The waste site was a newly level bench at about 3840 m A.S.L. (about 330 m above tree line). Winter snow cover persisted later in the spring than for the other sites. Coarse fragment content was about 75% with the fine fraction having a sandy loam texture.

Seed was collected by hand from native stands in the vicinity of the mine and in Rocky Mountain National Park. The individual species plots were fertilized with 18-46-0 at a rate of 336 kg/ha. The subsoil plots were fertilized with sewage sludge at 22 Mg/ha and the rock waste was fertilized with sewage sludge at 66 Mg/ha. Both the topsoil and subsoil plots were covered with straw mulch (4.5 Mg/ha) and then covered with plastic netting.

Establishment and persistence of most species seeded in topsoil was good (Table 13). The frequencies of *Agropyron scribneri*, *Androsace septentrionalis*, *Festuca thurberi*, *Hymenoxys grandiflora*, and *Rumex* spp. decreased, while *Poa glauca*, *Antennaria rosea*, and *Polygonum bistortoides* increased. Three of the forbs *Antennaria rosea*, *Polygonum bistortoides*, and *Potentilla diversifolia* had significant increases in ground cover from 1980 to 1985.

The native seed mixture was seeded at a rate of 8.6 kg/ha (1350 PLS/m^2). Of the 16 species seeded on the subsoil and waste rock sites, four species had much greater frequencies than the others (Table 14). Of these, *Deschampsia caespitosa* did not change in frequency from 1980 to 1985 while *Phleum alpinum* and *Poa alpina* increased on both subsoil and rock waste, and *Trisetum spicatum* increased on the subsoil. These four species have performed well in other alpine seedings (Brown and Johnston 1979) and are common colonizers on alpine disturbed sites with winter snow cover. Of the

Table 13. Seeding rate, calculated plant density, vegetation ground cover, and frequency of introduced species planted as monocultures in topsoil.

	Viable Seed Planted in 1978 (No./m^2)	Calculated Plant Density (No./m^2)	Vegetation Ground Cover (%)		Frequency within 10 X 10 cm Quadrats (%)	
		1985	1980	1985	1980	1985
Graminoids						
Agropyron latiglume	300	78	8	20 ns[c]	66	54 ns
Agropyron scribneri	7	1	2	0	38	1 [a]
Carex atrata	1400	9	0	1	1	9
Carex ebenea	2900	63	1	22 [b]	40	47 ns
Deschampsia caespitosa	4700	147	9	56 ns	81	77 ns
Festuca thurberi	2200	71	3	16 [b]	87	51 [a]
Phleum alpinum	2900	161	10	41 [b]	78	80 ns
Poa alpina	10600	281	17	59 [b]	83	94 ns
Poa glauca	1500	117	8	39 [b]	53	69 [a]
Trisetum spicatum	3000	253	11	28 ns	83	92 ns
Forbs						
Androsace septentrionalis	12500	4	7	1	79	4 [a]
Antennaria rosea	8300	143	8	28 [b]	57	76 [a]
Artemisia arctica	27500	53	4	12 ns	33	41 ns
Castilleja spp.	5700	1	0	1	1	1
Geum rossii	1600	65	1	10 ns	40	48 ns
Hymenoxys grandiflora	2600	34	1	8	52	29 [a]
Mertensia viridis	70	4	<1	1	8	4
Oxyria digyna	1500	67	10	9 ns	63	49 ns
Polemonium viscosum	800	37	1	4	39	31 ns
Polygonum bistortoides	unknown	62	3	11 [b]	23	46 [a]
Potentila diversifolia	6900	127	6	44 [b]	63	72 ns
Rumex spp.	1900	31	2	7	52	27 [a]
Trifolium dasyphyllum	70	2	0	0	2	2

[a] Frequency is significantly different ($P<0.05$) between years by Chi-square test; when frequency <10% for both values Chi-square not calculated.
[b] Ground cover is significantly different ($P=<0.05$) between years by F test.
[c] Not significant.
Source: Guillaume et al. (1986).

Table 14. Native species frequency in 1980 and 1985 on subsoil and rock waste sites seeded to a mixture of native species in 1978.

	Viable Seed Planted in 1978	Frequency			
		Subsoil 10 X 10 cm Quadrats		Rock Waste 20 X 20 cm Quadrats	
		1980	1985	1980	1985
	(number/m^2)	%			
Graminoids					
Agropyron latiglume	10	2	3	4	<1
Carex spp.	100	3	2	2	8
Deschampsia caespitosa	280	15	15 ns[b]	23	23 ns
Festuca thurberi	60	<1	<1	0	4
Phleum alpinum	180	9	16[a]	16	32[a]
Poa alpina	240	16	33[a]	20	53[a]
Poa glauca	0	0	<1	0	6
Poa reflexa	0	0	1	0	38[a]
Trisetum spicatum	120	13	21[a]	20	22 ns
Forbs					
Achillea lanulosa	0	0	<1	0	0
Androsace septentrionalis	8	1	<1	0	0
Artemisia arctica	30	1	<1	0	<1
Castilleja spp.	110	0	<1	0	<1
Geum rossii	12	0	<1	<1	0
Hymenoxys grandiflora	6	0	0	0	0
Lepidium spp.	0	<1	<1	<1	0
Oxyria digyna	0	<1	<1	0	<1
Polemonium viscosum	30	<1	<1	2	2
Polygonum bistortoides	0	<1	<1	1	<1
Potentilla diversifolia	110	<1	1	<1	1
Rumex spp.	50	3	1	1	<1
Taraxicum spp.	0	0	<1	0	0
Trifolium dasyphyllum	0	0	<1	0	0

[a] Frequency is significantly different ($P<0.05$) between years within a site by Chi-square test; when frequency <10% for both years Chi-square was not calculated.
[b] Not significant.
Source: Guillaume et al. (1986)

species not seeded, *Poa reflexa* was found on the waste rock site in significant amounts. The frequency of forbs in the mixed planting plots was very low. Apparently they could not compete with the grasses when sown in a mixture. Although low in frequency, individual plants of *Potentilla diversifolia* had outstanding vigour.

Seed was harvested from a nearby alpine meadow and seeded into subsoil. After six growing seasons *Deschampsia caespitosa*, *Phleum alpinum*, *Poa alpina*, *Trisetum spicatum*, *Agropyron latiglume*, *Carex* spp., *Poa glauca*, and the forb *Achillea millefolium* had frequencies greater than 10%.

In summary, the native grasses *Deschampsia caespitosa*, *Phleum alpinum*, *Poa alpina*, and *Trisetum spicatum* performed best. Native forbs showing promise included: *Achillea millefolium*, *Antennaria rosea*, *Polygonum bistortoides*, and *Potentilla diversifolia*. Other species with potential for use included: *Agropyron latiglume*, *Poa glauca*, *Poa reflexa*, and *Carex* spp.

Walker et al. (1977) reported on a study to select grass species native to the mountain regions of Alberta suitable for use in reclamation and wildlife range improvement. Approximately 1800 specimens representing 25 native grass species were collected from 60 sites in the Rocky Mountains and transplanted to field plots at Ellerslie near Edmonton during 1974 to 1976. Native grasses were initially selected on their ability to invade alpine and subalpine disturbances (Sadasivaiah and Weijer 1979). Species and strains were then evaluated according to the following criteria: wide adaptability, high seed production, high forage value, low seed shattering, even ripening, large seed size, winter hardiness, plant vigour and growth habit, tillering habit, heading date, disease and insect resistance, low biomass production, and uniform growth and maturity.

Spikes from individual plants were harvested when they matured to study the variability with regard to number of productive tillers, seed yield, and harvest date. Initial results indicated that some species such as *Stipa columbiana* and *Phleum alpinum* have an intermittent tillering habit in which seed heads ripen one at a time throughout the growing season. Some species such as *Poa alpina* and *Agrostis scabra* tended to produce two distinct crops in a growing season. Most other species evaluated produced seed heads which ripen over a period of a few days to several weeks. Other factors prohibiting large scale production of native grass seed were noted. These included seed

shattering, low yields, presence of hairs and awns, low fertility, and uneven ripening.

Poa interior (interior bluegrass) was found to be superior in its ability to survive and reproduce in a wide variety of environments in the Rocky Mountain region of Alberta. This species also yields two seed crops in one growing season (Sadasivaiah and Weijer 1980).

The Department of Genetics, University of Alberta, under contract to RRTAC and the Canadian Parks Service undertook selections from lines of native grasses suitable for reclamation in the alpine: *Agropyron dasystachyum*, *A. latiglume*, *A. riparium*, *A. subsecundum*, *A. trachycaulum*, *Agrostis scabra*, *Deschampsia caespitosa*, *Festuca altaica*, *F. saximontana*, *Koeleria cristata*, *Phleum alpinum*, *Poa alpina*, *P. artica*, *P. cusickii*, *P. interior*, and *Trisetum spicatum* (Weijer and Weijer 1983).

Selections were made over a period of 7 years or three selection cycles. *Deschampsia caespitosa* and *Poa interior* were considered particularly promising for development of cultivars tolerant of high alkaline or acid soil conditions. *Hedysarum sulphurescens*, *H. alpinum*, and *H. mackenzie* were considered useful for reclamation of disturbances above 1829 m.

Weijer and Weijer (1983) considered that *Dryas* species (particularly *D. drummondii* and *D. hookeriana*) were suitable for reclamation purposes. Both species are found in the alpine in Alberta acoording to Weijer and Weijer (1983). They are relatively fast growing species which form a very dense mat with excellent erosion controlling capacity. *D. hookeriana* is found in the high alpine on exposed sites and it appears to tolerate infertile rocky sites. *D. drummondii* is a pioneering species on dry river beds and disturbed sites.

Festuca saximontana has shown promise on Parker's Ridge, Alberta (pers. comm. Gail Harrison, Canadian Parks Service).

Several species were found to be successful when planted on tailings in the subalpine (2910 m A.S.L.) at Silverton, Colorado. Plots were irrigated and fertilized. The most promising species are described below (Hassell 1982):

1. *Elymus giganteus* var. Volga (mammoth wild rye) is a robust grass with strong stems and vigorous rhizomes. Plants were successfully established using transplants, and spring and fall direct seedings. Mammoth wild rye showed good vigour and

spread by rhizomes at this difficult site. It provided surface protection for other plants.

2. *Artemisia ludoviciana* (Louisiana sagewort) has performed well on the slope plots or in protected areas. This low shrub produced seed and spread about 25 cm by rhizomes the first year. The second and third year, the mature plants provided a micro-environment for other perennial plants to grow. Native seedlings became established and wheatgrasses started to crowd out the original *Artemisia* plants.
3. *Potentilla fruticosa* (shrubby cinquefoil) is a native plant usually found in high mountain meadows and stream bottoms from foothills to alpine zone. At Silverton it grew well on sandy tailing material. Selected accessions showed good performance and it appears adapted for reclamation work at other high elevation test sites.
4. *Potentilla diversifiolia* (varileaf cinquefoil) is a perennial plant with mostly basal leaves. It is found in high mountains in Colorado at 2100 to 3600 m A.S.L.
5. *Rosa* spp. (Rose) and *Salix* spp. (Willow) also showed good potential at the Silverton study site.

Brown and Chambers (1989) provided a list of those native alpine species that have successfully been established on disturbed sites from seeds, together with others that have favourable characteristics for revegetation (Table 15).

Many of the species listed have broad ecological amplitudes and occur as frequent colonizers on alpine disturbances. Also, many have high reproductive rates and easily collected seeds.

Establishment trials have tended to concentrate on early seral dominant species. However, inclusion of late seral dominant species may increase the species diversity and possibly accelerate the rate of succession (Chambers et al. 1984). Brown and Chambers (1989) noted that reclamation success may be improved when mixtures of species are planted that represent different life histories and physiological traits.

Table 15. Native alpine species suitable for revegetation. Those species marked with an asterisk have been successfully established on disturbed alpine sites from seed.[a]

Grasses and Grasslike Plants:

Agropyron trachycaulum (slender wheatgrass)
A. Scribneri (Scribner wheatgrass)
Carex paysonis (Payson sedge)
Deschampsia caespitosa (tufted hairgrass)
Phleum alpinum (alpine timothy)
Poa alpina (alpine bluegrass)
P. epilis (skyline bluegrass)
P. rupicola (timberline bluegrass)
Trisetum spicatum (spike trisetum)

Forbs:

Achillea millefolium (western yarrow)
Agoseris glauca (pale agoseris)
Arenaria obtusiloba (alpine sandwort)
A. scopulorum (alpine sagebrush)
Cerastium arvense (mouse-ear chickweed)
C. beeringianum (alpine chickweed)
Geum rossii (alpine avens)
Lupinus argenteus (silvery lupine)
Potentilla diversifolia (verileaf cinquefoil)
Senecio fremontii (Freemont groundsel)
Sibbaldia procumbens (prostrate sibbaldia)
Smelowskia calycina (alpine smelowskia)
Solidago multiradiata (mountain goldenrod)
Trifolium dasyphyllum (whiproot clover)
T. parryi (Parry clover)

[a] Adapted from original tables in Brown and Chambers (1989), Brown et al. (1978a, 1988), Chambers (1987, 1989a) and Chambers et al. (1984, 1988)

5.6.3 Introduced Species Tested In Revegetation Trials

Gates (1962) conducted one of the early studies on high altitude revegetation in Idaho. The revegetation trials were located at 2134 m A.S.L. on southeast slopes of 6 to 33° (10% to 65%), completely denuded as a result of grazing and trampling. Soils had a 30% coarse fragment content and slopes were very unstable. Vegetation on adjacent areas comprised *Stipa columbiana* (needlegrass), *Trisetum spicatum* (spike wheatgrass), *Deschampsia caespitosa* (tufted hairgrass), *Carex geyeri* (sedge), *Lupinus* sp. (lupine), and *Eriogonum* sp. (wild buckwheat). Equal portions of *Dactylis glomerata* (orchardgrass), *Agropyron trachycaulum* (slender wheatgrass), *Bromus inermis* (smooth brome), *Bromus marginatus* (mountain brome), *Phleum pratense* (timothy), and *Festuca idahoensis* (Idaho fescue) were broadcast seeded at 28 kg/ha. Plots were then fertilized at various rates and some plots mulched with two depths of sawdust, evergreen boughs, native hay, or asphalt emulsion. Except for the native hay plot, seeding in all mulch treatments failed. Native hay held down by chicken wire and boughs resulted in good establishment of native grasses (from seeds in the hay). Field application of fertilizer did little to increase grass emergence and had no effect on seedling survival. In almost all cases agronomic species were total failures on this site. Indigenous grasses, however, established as a result of the native hay did very well, showing importance of plant adaption to specific sites.

Brown et al. (1976) conducted revegetation studies at the McClaren mine on the Beartooth Plateau, using both native colonizers and commercial seed mixtures. At the end of the first growing season introduced grasses were taller, had higher production levels, and generally were more vigorous than native grasses. However, by the third growing season, the productivity and vigour of the introduced grasses had declined. The native grasses were much more vigorous, had greater productivity, and had even begun to invade plantings of introduced grasses. When transplanting native and introduced grasses in the same area, Brown and Johnston (1978) found that the native plants had an average first year survival rate of 75%, whereas the introduced species had only 39%. Also the native species had a higher level of productivity.

Guillaume et al. (1986) tested ten agronomic species on topsoil, subsoil, and rock waste at the Climax mine, Colorado. The site is described in section 5.6.2. Nine of the ten introduced species established readily when

seeded as monocultures in topsoil. Five years later the frequencies of *Alopecurus arundinaceus*, *Festuca ovina*, *F. rubra*, and *Poa pratensis* were unchanged while *Agrostis alba*, *Bromus inermis*, *Dactylis glomerata*, *Phleum pratense*, and *Trifolium repens* decreased. However, cover increased significantly for *Alopecurus arudinaceus*, *Festuca rubra*, and *Poa pratensis* (Table 16).

When the same ten species were seeded in mixture, in subsoil, or rock waste the *Festuca* species (*F. ovina* plus *F. rubra*) and *Poa pratensis* were the only species to increase in frequency on both substrates. These species were also the only species with good vigour after 5 years, and *Poa pratensis* was spreading by rhizomes on the high fertility treatments. None of the introduced species produced seed heads. *Alopecurus arundinaceus* tended to persist and increase in cover on the topsoiled plots but decreased in the subsoil and waste rock pile. The authors noted that in other trials *A. arundinaceus* grew well and spread by rhizomes on moist fertile sites in the upper subalpine but barely persisted on infertile drier sites.

Errington (1979) tested the growth and survival of agronomic species in trials established in 1977 and 1978 in the Peace River Coal Block of British Columbia. Four experimental plots (three in the alpine and one in the subalpine) were established in 1977. Elevations of the sites ranged from 1125 m to 1870 m A.S.L. Parent materials were variable and included till, colluvium and colluvium-shale. Soil textures were silty to sandy loams with varying coarse fragment contents. Individual species tested are given in Table 17 and the species mixtures tested are given in Table 18. One alpine site was seeded in September and the remaining sites were seeded in July. Four rates of fertilizer were applied at the time of seeding (Table 19).

Large variations in the survival and growth of the individual agronomic species was observed at one of the alpine sites (1720 to 1870 m A.S.L.). The most successful agronomic species tested on alpine sites included: Boreal creeping red fescue, Climax timothy, Tracenta bentgrass, meadow foxtail, and Kentucky bluegrass.

Table 16. Seeding rate, calculated plant density, vegetation ground cover, and frequency of introduced species planted as monocultures in topsoil.

	Viable Seed Planted in 1978 (No./m^2)	Calculated Plant Density (No./m^2)	Vegetation Ground Cover (%)		Frequency within 10 X 10 cm Qadrats (%)	
		1985	1980	1985	1980	1985
Grasses						
Agrostis alba	17700	0	6	0	99	0 [a]
Alopecurus arundinaceus 'Garrison'	1630	190	8	34 [b]	88	85 ns[c]
Bromus inermis 'Manchar'	360	16	4	0	80	15 [a]
Dactylis glomerata 'Potomac'	1200	31	5	11 ns	89	27 [a]
Festuca ovina 'Durar'	1490	204	16	37 ns	91	87 ns
Festuca rubra 'Pennlawn'	2140	212	17	48 [b]	91	88 ns
Phleum pratense 'Climax'	3620	87	17	15 ns	88	58 [a]
Poa pratensis 'Newport'	7100	139	6	28 [b]	91	75 ns
Legumes						
Astragalus cicer 'Lutana'	900	<1	0	0	4	<1
Trifolium repens	4420	0	6	0	73	0 [a]

[a] Frequency is significantly different ($P<0.05$) between years by Chi-square test.
[b] Ground cover is significantly different ($P<0.05$) between years by F test.
[c] Not significant.
Source: Guillaume et al. (1986)

Table 17. Agronomic species tested in plot trials, Peace River Coal Block.

Common Name	Scientific Name
Creeping red fescue - Boreal	*Festuca rubra L.*
Meadow fescue	*Festuca elatior L.*
Hard fescue	*Festuca ovina var. duriuscula (L.) Koch*
Kentucky bluegrass - Nugget	*Poa pratensis L.*
Canada bluegrass - Rubens	*Poa compressa L.*
Perennial ryegrass - Manhattan	*Lolium perenne L.*
Tracenta bentgrass	*Agrostis sp.*
Crested wheatgrass - Nordan	*Agropyron cristatum (L.) Gaertn.*
Pubescent wheatgrass	*Agropyron trichophorum (Link) Richt.*
Slender wheatgrass	*Agropyron trachycaulum (Link) Malte*
Streambank wheatgrass	*Agropyron riparium Scribn & Smith*
Bromegrass	*Bromus inermis Leyss*
Orchardgrass - Chinook	*Dactylis glomerata L.*
Redtop	*Agrostis alba L.*
Reed canarygrass	*Phalaris arundinacea L.*
Russian wild ryegrass	*Elymus junceus Fisch*
Timothy - Climax	*Phleum pratense L.*
Meadow foxtail	*Alopecurus pratensis*
Alfalfa - Ceres	*Medicago sativa L.*
Alfalfa - Drylander	*Medicago sativa L.*
Alsike clover	*Trifolium hybridum L.*
Red clover - Single cut	*Trifolium pratense L.*
Birdsfoot trefoil - Broad leaf	*Lotus corniculatus L.*
Sweet clover	*Melilotus sp.*
White clover	*Trifolium repens L.*
Cicer milkvetch	*Astragalus cicer L.*
Sainfoin - Melrose	*Onobrychis viciifolia Scop.*

Source: Errington (1979).

Table 18. Species mixes tested in plot trials, Peace River Coal Block. Both mixes were seeded at 56 kg/ha.

Mix	Species	% Composition
A	Creeping red fescue - Boreal	40
	Timothy	20
	Alsike clover	40
B	Creeping red fescue - Boreal	20
	Timothy	10
	Alsike clover	20
	Redtop	20
	Meadow foxtail	20
	Bromegrass	10

Source: Errington (1979)

Table 19. Fertilizer rates applied in plot trials, Peace River Coal Block.

Rate (kg/ha)		
N	P	K
0	0	0
18	22	11
36	45	22
72	90	45

Source: Errington (1979)

Most grass species responded to increased applications of fertilizer. Those species capable of sustaining a reasonable growth rate at the lower fertilizer application rate were: meadow foxtail, Hard fescue, pubescent wheatgrass and bromegrass. Legume growth in the alpine was generally very poor. Errington (1979) attributed this to their lack of winter hardiness.

Results from the species mixture trials indicated that plant growth varied according to the fertilizer rate and site location. Generally, growth increased with additional applications of fertilizer. Alsike clover, the only legume component of the mixtures tested, grew poorly at all sites.

At the subalpine site (1125 m A.S.L.), excellent growth was exhibited by all grass species tested. All legumes tested survived and had moderate growth in the subalpine plots. Ceres alfalfa and sweet clover appeared to be the most successful. Red clover, Alsike clover, Drylander alfalfa, and white clover exhibited good growth, especially when fertilized. Sainfoin growth was moderate at the higher rates of fertilizer application. Cicer milkvetch and birdsfoot trefoil grew poorly. The species mixes performed well at all fertilizer rates in the subalpine. Increased applications of fertilizer promoted the growth of grass species at the expense of legumes.

In a separate trial, Errington (1979) tested species germination, growth, and survival in an unfertilized plot at 1800 m A.S.L. in the Peace River Coal Block, British Columbia. The trial site was located on a south aspect in a dry tundra vegetation type. Soils were sandy loam textured and formed in colluvium. The plot was seeded on July 5, 1976. The seeding rate was not reported. Table 20 lists the species seeded. Two years after seeding (August 1978) only seven of the 23 species seeded had survived, none of which were legumes. The species that performed best were: Boreal creeping red fescue, Oasis chewings fescue, and Park Kentucky bluegrass.

Ziemkiewicz (1977) established species test plots on Harmer Ridge in British Columbia at 2200 m A.S.L. The trials were established in 1972 and 1973. All species sown on the site were agronomics. Those that proved most successful were: *Festuca rubra* (red fescue), *Agrostis alba* (redtop), *Bromus inermis* (smooth brome), *Alopecurus pratensis* (meadow foxtail), *Dactylis glomerata* (orchardgrass), *Phleum pratense* (timothy), *Poa pratensis* (Kentucky

Table 20. Plant species tested in an unfertilized trial at 1800 m A.S.L. Peace River Coal Block, northeastern British Columbia.

Common Name	Scientific Name
Crested wheatgrass - Fairway	*Agropyron cristatum*
Streambank wheatgrass - Sodar	*Agropyron riparium*
Pubescent wheatgrass - Greenleaf	*Agropyron trichophorum*
Intermediate wheatgrass - Chief	*Agropyron intermedium*
Slender wheatgrass - Revenue	*Agropyron trachycaulum*
Bromegrass - Carlton	*Bromus inermis*
Bromegrass - Magna	*Bromus inermis*
Meadow fescue - Miner	*Festuca pratensis*
Hard fescue - Bijant	*Festuca ovina*
Creeping red fescue - Boreal	*Festuca rubra*
Chewings fescue - Oasis	*Festuca rubra* var. *fallaz*
Kentucky bluegrass - Park	*Poa pratensis*
Meadow foxtail - Oregon common	*Alopecurus pratensis*
Reed canary grass - Castor	*Phalaris arundinacea*
Colonial bentgrass - Exeter	*Agrostis tenuis*
Timothy - Climax	*Phleum pratense*
Russian wild ryegrass - Sawki	*Elymus junceus*
Sainfoin - Melrose	*Onobrychis viciifolia*
Birdsfoot trefoil - Leo	*Lotus corniculatus*
Alfalfa - Beaver	*Trifolium sativa*
Alsike clover - Dawn	*Trifolium hybridum*
Red clover - Altaswede	*Trifolium pratense*
White clover - Nora	*Trifolium repens*

Source: Errington (1979)

bluegrass), and *Poa compressa* (Canada bluegrass). Native species that invaded the plot areas were: *Trisetum spicatum*, *Agropyron trachycaulum*, *Epilobium* sp., and *Agrostis scabra*.

Welin (1974) described a seed mixture recommended for revegetation of ski trails at Vail Mountain, Colorado (Table 21). This was based on several years of field trials. Observations on areas seeded in the past (seed mixture used was unknown) indicated that brome, orchardgrass, and perennial ryegrass were persistent. He found winter wheat was an excellent cover crop at all elevations. It provided a quick ground cover and in the succeeding spring grew strongly soon after snowmelt. He suggested that dandelion might be a suitable species for use in revegetation because it was found at all elevations, all aspects, and on very harsh or infertile sites.

Brown (1974) studied plant establishment at the Climax Mine in Colorado. Elevation range of the mine is 3450 m to 4500 m. Soils are thin and relatively infertile, and are derived from glacial till, with isolated scattered pockets of peat and sand deposits. Over 20 species of grasses were tested in plots at Climax. From the results, the species mixture in Table 22 was found suitable for seeding disturbed subalpine areas. This mixture is seeded at a rate of 34 kg/ha with 5.6 kg/ha to 11 kg/ha of 'Balbo' rye seeded as a nurse crop.

Ziemkiewicz (1977) described a revegetation trial on reclaimed coal mine spoil at Sparwood, British Columbia. Fifteen agronomic species were seeded on nine representative reclaimed sites. The site with the highest elevation was at 2100 m A.S.L. (lower alpine). Details regarding site preparation were not given. After two growing seasons, species productivity was assessed based on above ground biomass. Species exhibiting significant increases in biomass production over a 2 year period included: *Bromus inermis* (smooth brome), *Dactylis glomerata* (orchardgrass), *Festuca rubra* (red fescue), *Lolium perenne* (perennial ryegrass), *Phleum* spp. (timothy), and *Medicago* spp. (alfalfa). *Agrostis scabra* (Redtop), *Poa pratensis* (Kentucky bluegrass), *Melilotus alba* (sweet clover), and *Trifolium repens* (white clover) had poor establishment after two growing seasons.

Table 21. Seed mixes recommended for revegetation of ski trails at Vail Mountain, Colorado.

Below 3048 m A.S.L.	Above 3048 m A.S.L.
20% Smooth Brome (Manchar)	20% Smooth Brome (Manchar)
20% Intermediate Wheatgrass	20% Slender Wheatgrass
15% Orchardgrass	15% Timothy
15% Bluegrass	15% Bluegrass
15% Clover (alsike or white)	15% Meadow Foxtail
15% Winter Wheat	15% Perennial Ryegrass

Source: Welin (1974)

Table 22. Species mixture for seeding disturbed subalpine areas at Climax Mine, Colorado.

Species	Percent of Mixture	Species	Percent of Mixture
Hard Fescue	10	Smooth Brome	20
White Clover (Dutch)	10	Timothy	15
Orchardgrass	10	Redtop	15
Meadow Foxtail	10	Red Fescue	10

Source: Brown (1974)

Hendzel (1976) described a number of revegetation projects on disturbed sites conducted by the U.S. Forest Service within the central and northern portions of the Rocky Mountains in southwestern Montana. Two sites were chosen for the rehabilitation of wildlife range: Carrot Basin (3100 m A.S.L.) and Cabin Creek (2833 to 3000 m A.S.L.). Site preparations included spraying with aerial applications of 2, 4-D to reduce weedy competition (Carrot Basin site only), and scarification. *Bromus inermis* (smooth brome), *Agropyron trachycaulum* (slender wheatgrass), *Poa pratensis* (Kentucky bluegrass), and *Alopecurus pratensis* (meadow foxtail) were seeded at rates of 16.8 kg/ha and fertilized with a high nitrogen content fertilizer at a rate of 111 kg/ha. Assessment after ten growing seasons indicated that *Bromus inermis* and *Agropyron trachycaulum* were the only species found persisting at both sites, however, *Bromus inermis* did not produce viable seed.

In a separate study, 40 grasses were seeded on fertile soils at 3117 m A.S.L. Seed was collected from low elevation sources except for mountain brome (which was collected on-site). Site preparations consisted of plowing, disking, and harrowing. After a 10 year growth period, the following grasses maintained or increased: *Bromus inermis*, *Alopecurus pratensis*, *Bromus erectus*, *Poa pratensis*, *Agropyron subsecundum*, *Agropyron trachycaulum* and *Agropyron violaceum*. The grasses which responded well for 9 years, but had a rapid decline in the tenth year were: *Festuca ovina duriuscula*, *Agropyron cristatum* var. Fairway, *Agropyron dasystachyum*, *Festuca rubra*, *Elymus junceus*, and *Bromus marginatus*. Common indigenous species which failed within 3 years were: *Festuca scabrella*, *Agropyron spicatum*, and *Poa ampla*.

Two additional trials were conducted on various disturbed sites in the vicinity at the same elevations. On both sites, *Alopecurus pratensis* and *Bromus inermis* responded well to fertilizer and mulch treatments.

Revegetation trials were also established on a mine site at 3000 to 3167 m A.S.L. Site preparations included recontouring, seeding, fertilizing (10-25-0) at application rates of 22.7 kg/ha, and wood mulching. Good performance was demonstrated by *Alopecurus pratensis* on this site. *Festuca ovina* var. *duriuscula*, *Festuca commutata*, and *Poa pratensis* demonstrated fair success, while *Trifolium repens* had poor success. *Bromus inermis* did very poorly on this site. In summary, *Bromus inermis* and *Alopecurus pratensis*

proved to be the best agronomic species for revegetation of disturbed sites at these elevations in southwestern Montana.

Takyi and Islam (1985b) evaluated 21 agronomic species on disturbed overburden fertilized to provide 112 kg/ha N, 67 kg/ha P, and 34 kg/ha, at Tent Mountain (2133 m A.S.L.) in southern Alberta. First year plant cover for all species averaged 37% and ranged from a low of 10% to 20% to a high of 95%. After 3 years, the following species still provided adequate plant cover: *Agropyron pectiniforme* var. Nordan (50%), *Agropyron pectiniforme* var. Fairway (28%), *Festuca ovina* (32%), *Festuca rubra* var. Arctared (25%), *Poa pratensis* var. Troy (34%), and *Agrostis alba* (35%). A slope failure destroyed a portion of the test site following the second growing season. Species, in addition to those already mentioned, which produced adequate cover after the second year included: *Festuca rubra* var. Boreal (60%), *Poa compressa* (44%), *Poa pratensis* var. Nugget (60%), *Agrostis alba* var. Emerald (83%), *Elymus junceus* (38%), and *Dactylis glomerata* var. Tardus (42%).

On overburden top-dressed with 7.5 to 10 cm of mineral soil adequate fifth year plant cover was provided by *Festuca rubra* (43%), *Festuca rubra* var. commutata (32%), *Festuca brachyphylla* (26%), *Poa pratensis* (27%), *Poa compressa* (24%), and *Agrostis alba* (27%). On raw overburden, the above-mentioned species plus *Poa interior* (31%) and *Bromus inermis* (34%) produced adequate cover.

Mitchell (1987) tested a number of plants on coal mine overburden materials in the interior of south-central Alaska on sites located well below timberline to sites in the alpine region. With proper fertilization, a number of grasses were found to maintain adequate cover for soil stabilization purposes over the 5 to 7 years of the various trials. The consistently good performers above timberline were: *Festuca rubra* var. Arctared (Boreal or Pennlawn second choice), *Festuca ovina* var. Scaldis or Tournament, *Deschampsia caespitosa* var. Nortran, *Deschampsia beringensis* var. Norcoast, *Arctagrostis latifolia* var. Kenai or Alyesko, *Poa pratensis* var. Nugget, and *Calamagrostis canadensis* var. Sourdough.

Carlson (1986) recommended that erosion control seed mixtures for high elevation should include:

1. Rapidly developing, usually short-lived grasses with strong fibrous root systems. These species will not persist and give way to longer-lived components.
2. One or more persistent perennial grasses each with special tolerances that compliment each other.
3. One or more forbs, preferably including at least one legume to provide nitrogen. These plants may also provide initial cover.
4. One or more shrubs (optional). Shrubs usually use moisture deeper in the soil profile.

He described the following species as suitable for providing erosion control:

<u>Grasses for rapid initial cover:</u>

1. *Bromus marginatus* (mountain brome)
   Bromar mountain brome was found to provide adequate cover on high elevation sites in the Colorado Rocky Mountains. The Environmental Plant Centre (EPC) at Meeker, Colorado has selected five new strains of mountain brome with superior characteristics to "Bromar". These are currently being tested and a new cultivar will released in the early 1990's (Garry Noller, Upper Colorado Environmental Plant Centre, Meeker, Colorado; telephone call April 23, 1990).
2. *Agropyron trachycaulum* (slender wheatgrass)
   The San Luis cultivar was released in 1984 based on its performance at high elevations. It establishes well and is persistent, compared to other varieties. 'San Luis' is recommended for soil stabilization on disturbed sites above 1829 m A.S.L. in Colorado on sites receiving 35 cm or more annual precipitation. It has performed well at 3400 m A.S.L. in central Colorado. (Garry Noller, Upper Colorado Environmental Plant Centre, Meeker, Colorado; letter dated April 26, 1990.)
3. *Agropyron scribneri* (Scribner wheatgrass)
   This species is well adapted to extreme altitudes.

4. *Elymus glaucus* (blue wildrye) and *E. elymoides* (squirreltail)
   These native species are currently being evaluated and are adapted to high elevations.
5. *Agropyron dasystachyum* (thickspike wheatgrass)
   The variety "Critana" originates from collections at low elevations.

Grasses for long-term cover:

Bromus inermis, *Festuca arundinacea*, *Festuca rubra*, *Festuca ovina* var. *duriuscula*, and *Agropyron intermedium* are introduced grasses that have persisted well with proper management on high elevation sites. *Festuca rubra* and *Festuca ovina* var. *duriuscula* are considered suitable because they are tolerant of harsh sites, are low growing and form tight stands.

Carlson (1986) considered that a systematic evaluation of the following fescues would be useful: *F. ovina*, *F. idahoensis*, *F. arizonica*, *F. occidentalis*, *F. thurberi*, *F. viridula*, *F. scabrella*, and *F. californica*.

Deschampsia caespitosa is a widely adapted species found on moist subalpine to alpine ridges and slopes in the mountains of the western United States. Several superior accessions have been developed at the Meeker EPC, which have shown good performance on several high altitude sites. A new variety is presently being released but is not yet named (Garry Noller, Upper Colorado Environmental Plant Centre, Meeker, Colorado; telephone call April 23, 1990).

Elymus triticoides is a native grass that has been found growing on hard rock mine tailings at high altitudes in the Rocky Mountains. A related agronomic species Volga giant wildrye has performed well at the Silverton mine tailings in Colorado.

Three accessions of *Stipa nelsonii* have been selected at the Meeker EPC for evaluation. *Phleum alpinum* is also being evaluated but its low seed production is proving a limitation. According to Carlson (1986) little or no selection work is being conducted with *Poa alpina*, *Trisetum spicatum*, or sedges (*Carex* spp.). *Poa compressa* var. Ruebens has performed well at high elevation sites.

5.6.4 Forb Species

The introduced forb species *Melilotus* spp. (sweet clover), *Medicago sativa* (alfalfa), *Trifolium* spp. (clover), *Lotus* spp. (trefoil), and *Astragalus cicer* (cicer milkvetch) have been tested at high elevation sites. *Astragalus cicer* var. Monarch has performed very well at high elevation (Carlson 1986).

Berg and Barrau (1978) noted that legume establishment is usually sparse on high altitude sites. This was related to several factors:

1. Legumes do not have as much seedling vigour as grasses.
2. Legumes are more sensitive to the marginal plant-available phosphorous and potassium levels sometimes found in the coarse-textured soils.
3. On soils in the pH range of 4.5 to 5.5 grasses will survive but it is too acid for most legumes.
4. Coarse-textured soils have low water holding capacity and thus are a droughty media for legumes.
5. Legume species used are not well-adapted to the subalpine.

Establishment of several legume species was studied at the Climax Mine (3350 m A.S.L.), Colorado. All species were seeded at 28 kg/ha and inoculated with the appropriate *Rhizobium* bacteria. The results (Table 23) indicate that after one growing season *Astragalus cicer* was the only species to show adequate initial stand establishment. Seedlings of all species were found to be nodulated.

Astragalus cicer was found to be the only introduced legume that showed promise after ten growing seasons at Climax. The initial *Astragalus cicer* stands were sparse and growth was slow the first three growing seasons.

5.6.5 Establishment from Seed

5.6.5.1 Seed collection. Use of native alpine plants in revegetation above timberline is limited by the availability of seed, particularly those of well performing species. Seed output in alpine plants depends on environmental conditions and can vary dramatically from year to year (Urbanska 1985). Successful seed production is influenced by climatic conditions not only at the onset of seed setting but also at later phases. Chambers (1989a) found

Table 23. Legume plant density and height after one growing season.

Species	Plants/m of row	Height (cm)
Alsike clover	5.4	2.5 to 5.0
Alfalfa	2.4	2.5 to 10.0
Birdsfoot trefoil	2.2	1.3 to 2.5
Cicer milkvetch	15.5	1.3 to 2.5
Red clover	5.7	2.5 to 10.0
White clover	1.3	1.3 to 2.5

Source: Berg and Barrau (1978)

significant differences among years and species in seed fill for grasses, and viability for grasses and forbs for seed collected successively between 1983 and 1986 on the Beartooth Plateau in Montana. These differences were attributed to variability in climatic factors such as dates of snowmelt, timing and amount of precipitation, and ambient air and soil temperatures. Large differences among species in seed viability were found, usually with grasses having lower and more variable seed viability than forbs.

Seed maturity and production of native alpine plant species is highly variable from year to year, and collection must be opportunistic to take advantage of good seed production years for different species (Brown and Chambers 1989). Several years may be required to collect sufficient seed of all species needed for a given revegetation program. Seed should be collected in late summer or fall just prior to natural dispersal. This requires a knowledge of the phenology of the different plant species (Brown and Chambers 1989).

Grass seed can be hand collected by stripping seed directly from the inflorescence, or by clipping the entire culm followed by threshing. Seeds from forbs need to be separated from the fruity bodies and stored in

dry, porous containers in a cool dry environment maintained near 0°C. Storage conditions and seed longevity during storage must be monitored carefully (Chambers 1989b; Chambers et al. 1987b). Seed longevity of high elevation species may be improved if stored at -18°C at low moisture content (Billings and Mooney 1968).

A repeated harvest in the wild can damage natural populations, is not always reliable, and is expensive. Urbanska (1986) suggested that cultivation of selected alpine species at lower elevations would provide an increased supply of seeds with better germination and without recurrent damage to the natural populations.

Production of seed from native species can be expensive. *Agropyron latiglume* has a decumbent growth habit which makes harvesting very difficult. *Phleum alpinum* suffers from uneven ripening and *Poa alpina* has shown poor seed yields. Both *Trisetum spicatum* and *Calamagrostis purpurescens* possess small awns which make harvesting and processing difficult (Walker 1982).

5.6.5.2 Seed dormancy and germination. Almost all seed germination in alpine locations takes place in early summer after snowmelt during the year following seed production. This occurs after soil temperatures reach 10 or 15°C in the daytime, a week or so after snowmelt and before the soil dries out. Most germination in late summer is impeded by lack of moisture and low temperatures. Late soil moisture is available in most wet meadows and many of the principle species in such places have seed dormancy mechanisms: *Carex*, *Luzula*, *Erythronium*, *Saxifraga rhomboidea*, *Deschampsia caespitosa*, and *Polygonum bistortoides* (Billings 1974b). However, some plants in such wet places do produce seed that germinates the same year. For example, *Salix planifolia* var. *monica* in the Rocky Mountains ripen in July and germinate immediately in the wet habitat. Seeds of *Salix brachycarpa* do not ripen until August when it's site has become rather dry. These seeds over winter in viable form and germinate early the next summer (Bliss 1958).

Most alpine species lack a primary seed dormancy mechanism and the elapsed time between seed production and germination is environmentally imposed (secondary dormancy). *Carex*, *Trifolium*, and *Salix* are the principal genera having dormant seeds. The existence of seed dormancy in alpine plants has been demonstrated by several authors (Acharya 1989b; Amen 1986). The

commonest dormancy is caused by a hard and impermeable seed coat (e.g., *Carex*, *Luzula*, *Thlaspi*, and *Trifolium*). Seed dormancy is more common among dominant and abundant species in moist or wet alpine meadows (Amen 1966).

Many native alpine grass species have narrow germination requirements (Amen 1966). Johnson et al. (1965) have found this to be particularly true for *Carex* spp. Chambers (1987) examined the germination responses of several early and late seral dominant alpine species. Seed germination of the forbs studied (*Geum rossii*, *Artemisia scopulorum*, *Polemonium viscosum*, *Potentilla diversifolia*, and *Sibbaldia procumbens*) was greater under light than dark conditions and following wet, cold storage.

Scarification is frequently more effective than cold stratification for treatment of dormancy in alpine plant seeds (Urbanska 1986). Amen (1966) noted that there was apparent correlation between the scarification requirement exhibited by many of the dormant seed species and the abrasive action generally produced by solifluction and wind in the habitats where these species occur. Of those plants whose seeds require stratification, *Carex algonigra* occurs on disturbed open sites, *Carex scopulorum* and *Luzula spicata* on solifluction terraces, and *Trifolium nanum* occurs as a codominant in the cushion plant complexes which are usually snow-free and subject to severe winds.

Amen (1966) found that optimal temperatures for germination of alpine seeds mostly range from 18 to 22°C. He found no evidence to suggest that any alpine seeds can germinate at temperatures below 10°C. The germination requirements of some alpine plant species are given in Table 24.

The ecological advantage of seed dormancy is that germination might be spread over an extended period and therefore increase the likelihood of germination occurring during periods favourable for growth. In many alpine environments moisture conditions favourable for seed germination may only be present for periods of a few weeks (Sayers and Ward 1966). Plant genotypes capable of rapid seed germination might establish better than genotypes with lower rates (Acharya 1989a).

Knowledge of seed germination requirements of individual species is essential to determine seeding methods and other revegetation techniques (Brown and Chambers 1989). Many alpine forbs require light for germination, whereas grasses have less specific requirements (Chambers et al. 1987b).

Table 24. Alpine species where the nature of seed dormancy and the factors required for effective germination are known. Most of the germinability tests were conducted at room temperature (22°C).

SPECIES

Scarification Necessary

Androsace septentrionalis puberulenta
Carex albonigra
Carex scopulorum[a]
Epilobium halleanum
Luzula spicata
Thlaspi arvense
Trifolium nanum
Trifolium parryi

Stratification (-4°C) Necessary

Erythronium grandiflorum
Galium bifolium
Hydrophyllum fendleri

Promotive but unnecessary
Carex chalcioleis[a]
Carex ebenea

After-ripening
Cerastium beeringianum
Saxifraga rhomboidea

Photosensitivity

Dormant and light-requiring

Carex chaliciolepis
Carex ebenea
Carex scopulorum
Draba crassifolia
Kalmia polifolia microphylla
Polemonium viscosum

Non-dormant but light-inhibited

Calamagrostis purpurescens[a]
Festuca ovina
Poa longiligula
Trisetum spicatum

[a]Results were inconclusive and the author remained uncertain.
Source: Amen (1966)

These light-requiring species should be seeded on the soil surface following the planting and incorporation of other seeds (Haggas et al. 1987).

Acharya (1989a) studied factors affecting germination of *Poa alpina* (alpine bluegrass) and *Agropyron latiglume* (broad-glumed wheatgrass) seed from plants collected from several alpine and subalpine sites in the Rocky Mountains of Alberta. *Poa alpina* seeds germinated best under darkness and 16/8 h cycles of 22/15 °C temperature, while *Agropyron latiglume* seeds needed a 29/22 °C regime and darkness for best germination. However, final germination under the 16 h photoperiod exceeded germination in darkness. Alpine *Trisetum spicatum* also demonstrated a similar germination response to light and darkness (Sayers and Ward 1966). Both *Poa alpina* and *Agropyron latiglume* demonstrated high total germination and high rates of germination in these laboratory trials. The faster initial germination in darkness suggested that seed of these two species should be drilled rather than broadcast to ensure best results.

In contrast to some warm season forage grasses (Hsu et al. 1985) both *Poa alpina* and *Agropyron latiglume* appeared to have a threshold germination lower than 36 °C. Acharya (1989a) suggested that this may be an adaption to cooler high elevation environments. He also suggested that poor emergence for these grasses would result if they were seeded into dark mineral overburden during midsummer when mid-day temperatures can reach above 40 °C.

Both species exhibited primary dormancy and dormancy induced through unfavourable external conditions (secondary dormancy). It has been suggested that this may be a genetic adaptation to stressful alpine environments (Acharya 1989b).

For some alpine species the conditions under which the parent plants are grown, and especially the environmental conditions under which the seed matured, affected subsequent germination (Gutterman 1980; McCullough and Shropshire 1970; Urbanska and Schutz 1986). Seed germination of *Poa alpina* was mainly influenced by the environment under which germination occurred, but was also influenced by the population from which the seed originated (Acharya 1989a).

Urbanska (1986) found that germination was dependant on the source population. It was also found to be dependant on the environmental conditions accompanying seed development. She studied seed production and germinating

behaviour in plants transplanted in an experimental garden at 400 m A.S.L. and in plants from the original sites above timberline. In the year following transplanting, germination rates were higher in the garden grown seeds than in those harvested from the alpine populations.

Recently, Hermesh (in press) investigated the influence of maternal environment on subsequent seed germination of alpine bluegrass (*Poa alpina L.*). The experiments demonstrated that the maternal environment of the seeds had a greater effect on the subsequent germination than genotype. Alpine bluegrass seed originating from nursery plots at the Alberta Environmental Centre, Vegreville, germinated significantly earlier than the seed from the same lines grown in alpine environments. Viability of the seed from both sources was determined to be similar. Clones from plants collected at three elevations from Deadman Pass, Alberta (1500, 2000, and 2500 m A.S.L.) were grown under three temperature regimes in growth chambers. Seed produced in the cold growth chamber environment generally germinated at a slower rate and frequently displayed greater primary dormancy than that produced in the warmer environments. Seed weight was not correlated with germination as the seed produced in the warmer chambers was significantly lighter than seed produced in the cold chamber.

Seed for use in alpine reclamation requires high total germination and high rates of germination for the rapid establishment of a ground cover (Chambers et al. 1987a). However, seed harvested from alpine areas often has low rates of germination (Brown and Chambers 1989). Hermesh (1990) suggests that because high rates of germination result from a favourable maternal environment, seed for use in reclamation (having rapid germination and minimal dormancy) should be grown in nurseries under favourable environments.

Seed germination has also been shown to be influenced by the nature of the substratum. This needs to be taken into consideration during selection of appropriate growth medium (soil and overburden selection) (Urbanska 1986).

5.6.5.3 Seedling establishment. Although most species of alpine angiosperms set viable seed, seedlings are usually not numerous in alpine environments (Osburn 1958). Seedling establishment in the alpine is infrequent because:

1. Temperature must be warm enough for germination to take place, and this must coincide with favourable soil moisture conditions;
2. Germination must occur early enough in the summer to allow time for good growth prior to return of temperatures below freezing; and,
3. Seedlings cannot be exposed to drought in the latter half of summer before the root system has penetrated to a reliable water supply (Billings 1974a).

Since most seed germination in the tundra occurs in early summer, the seedling has only a few weeks to develop a root system and to produce enough carbohydrates to allow survival the following winter (Billings 1974a).

Early root initiation and rapid root extension is an advantage in alpine areas where high radiation loads and strong winds result in rapid drying of the surface soils. Since seedlings may not receive additional precipitation for 10 to 20 days after emergence, the ability to survive drought and resume growth after drought is also important (Johnson 1980). Urbanska (1986) noted that seedlings of some species found on scree slopes had very fast root growth. These included *Biscu1la levigata*, *Cirsium spinosissinum*, and *Doronicum grandiflorum*. Presumably the rapid root growth was an adaptation to the droughty habitat in which these species were found.

Safe site has been defined as a set of habitat conditions that favour germination and seedling establishment (Harper 1977). That is, a safe site provides conditions necessary for seedling establishment and also excludes environmental hazards. This concept can be used to describe conditions necessary for native alpine seedling establishment in the alpine (Table 25). This is a general description that may vary depending on the given alpine habitat and a particular species.

Osburn (1961) found that soil drought and needle-ice activity are the most important influences on seedling establishment in Colorado alpine areas. The differential survival of seedlings can have a profound effect on vegetation patterns.

Because alpine plants evolved under conditions of low nutrient status, a high soil nutrient status may not be essential for a safe site in the alpine. Conditions that produce surface stability and reduce the risk of

Table 25. Habitat conditions that favour germination and seedling establishment (safe sites) in the alpine.

Site features	Major environmental hazards from which safe site should protect
soil surface stabilized, at least temporarily	needle-ice formation
soil texture suitable for radicle penetration	frost heaving
sufficient soil moisture	wind
sufficient light	extreme fluctuation of soil surface temperature
nutrients (may be low or limiting)	overgrazing

Source: (Urbanska and Schutz 1986)

excessive frost and drought may be more important. These factors need to be considered during reclamation planning (site preparation and surface amendments).

Willard and Marr (1971) found that plant establishment from seed was not common on disturbed alpine tundra in Colorado. However, a large number of seedlings were noted in one year because of a favourable combination of unusually high soil moisture and warm weather from late June to late August. "Bursts" of seedlings in favourable years have been noted by other researchers (Bonde 1968, 1969; Osburn 1961).

Fossati (1980) found that protection by standing crop and plant litter may enhance the survival of seedlings in sun- and wind-exposed sites on acidic silicate materials. However, results from comparable habitats on dolomite were more variable. Willard and Marr (1971) found that the most favourable place for seedlings to develop on eroded hiking trails was along the margins of established plants. Bare humus soil was the microsite that supported the fewest seedlings, probably because of needle-ice activity in spring and fall, and desiccation under high summer temperatures. The survival of seedlings that germinated in bare soil was greater on exposed B and C horizons

than on the darker more friable and organic-rich A horizon. Mineral soil and litter covered surfaces had an intermediate number of seedlings.

Recruitment and mortality of *Arenaria groenlandica*, *Juncus trifidus*, and *Potentilla tridentata* were measured on disturbed alpine areas on Franconia Ridge (1524 m A.S.L.) in the White Mountains of New Hampshire Roach and Marchand 1984). Field collected seeds were sown onto hiker-disturbed and naturally-disturbed areas. Seedlings of A. *groenlandica* and *J. trifidus* began emerging about 15 days after being sown in mid-late June. Emergence of *P. tridentata* followed 2 weeks later. First year seedling emergence totalled 38%, 17%, and 6% for *A. groenlandica*, *J. trifidus*, and *P. tridentata* respectively. Recruitment from the overwintering seed population was more synchronized the following June, and emergence in that month nearly equalled that of the first year. Recruitment during the second year was 23% for *A. groenlandica*, 10% for *J. trifidus*, and 8% for *P. tridentata*. There was no additional germination in the third year and no natural seeding was observed during the trial. Seedling survival after two winters was very low; 0.95% for *A. groenlandica* and the other species were eliminated. Peaks in seedling mortality during the growing season (spring and fall) coincided with frost activity. *A. groenlandica* and *J. trifidus* were observed to establish from seed in adjacent closed communities and in areas on bare soil with high snow cover where there is less frost activity. The authors concluded that establishment can only be expected where there is minimal frost activity.

Plant establishment in the alpine can be very slow. Tiny true leaves may be produced the first year, but cotyledons often carry the plant through the first season by their photosynthesis. It may be several years before the young plant is firmly established (Billings 1974b). Establishment in high-alpine plants cannot be assessed by accumulation of aerial biomass alone, development of the root system being frequently more important for survival and exploitation of the low nutrient environment than an extensive photosynthetic surface (Urbanska and Schutz 1986).

5.6.5.4 Seeding methods. Hand seeding, broadcasting, and hydroseeding have all been used successfully for establishing alpine plants. Sadasivaiah and Weijer (1980) had good seedling establishment (almost 100%) for *Agropyron trachycaulum*, *A. subsecundum*, *A. dasystachyum*, and *A. riparium* using a V-belt

seeder with a 2 cm depth of seeding. These trials were undertaken at the University of Alberta research plots at Ellerslie. Species with lighter and smaller seed such as *Deschampsia caespitosa*, *Festuca saximontana*, *Phleum alpinum*, *Koeleria cristata*, *Poa interior*, and *Trisetum spicatum* had low and variable seedling establishment.

Brown et al. (1976) recommended that if seed is broadcast in alpine areas, the area should be raked to cover the seed and packed firmly. Firm packing, especially with a seed packer, ensures intimate seed contact with the soil and was considered by Brown et al. (1976) to be one of the most important steps in reclamation. They recommended that seed not be planted any deeper than 1.3 cm.

Viable seed in the top 2.5 cm of surface soil can germinate within 24 hours, but is susceptible to needle-ice and desiccation. This hazard is not as great near borders of existing vegetation, but can be severe in areas of bare, dark soil which have extreme radiant heat gain and loss (Willard 1976).

Several seeding methods were explored by Brown (1974) at the Climax Molybdenum Mine in Colorado. Elevation range for the mine is 3450 m to 4500 m A.S.L. Soils are infertile, derived from glacial till that contains pockets of peat and sand deposits. Seeding methods were matched with topography and site characteristics. Flat sites were broadcast seeded and fertilized, then lightly disced. On rougher terrain both seed and fertilizer were spread with a Helis five-bushel, single spinner seeder. A length of chain-link fence was used as a harrow after each application to mix fertilizer and soil, and to cover seed.

Hydroseeding was limited to steep slopes because of the cost. The hydroseeding mixture contained 180 kg of wood fibre, 4.5 kg of 12-12-12 fertilizer, 4.5 kg of seed mix, 2.3 kg of native seed, and 1.6 kg of ‘Balbo’ ryegrass. The latter was included as a nurse crop. This mixture could cover approximately 0.12 ha. Hydroseeding was found to be particularly successful where a seedbed could be prepared in advance. On slopes that could not be prepared, several applications during June, July, and September were required. Glacial till soils that tend to crust when hydroseeded were first prepared with a "klod buster". This spiked chain-like harrow broke up the soil crust and put a finished look on the slope.

Errington (1979) found that broadcast seeding without fertilizer applications resulted in poor growth in the alpine in the Peace River Coal Block in northeastern British Columbia. This technique, however, did result in satisfactory growth at most sites below treeline. Seedling establishment was greatly improved on those sites that were harrowed and fertilized. Hydroseeding also gave favourable results on the alpine sites.

5.6.5.5 Timing of seeding. Brown et al. (1976) considered that seeding of alpine disturbances should be done only in the fall, particularly if native species are included in the mixture. Later fall seeding ensures cold stratification of those plants requiring it. In addition, seed will be exposed to optimum environmental conditions the following spring during snowmelt. Alpine areas are generally inaccessible until late spring at which time conditions may not be favourable for germination and survival. Also fall usually provides more favourable working conditions for planting.

Thomson and Sembenelli (1987) noted that fall seeding allows use to be made of the entire growth period and at altitudes above 2000 m this could be as much as a 30% gain because of delay in access. In addition, by obtaining the earliest possible germination (15 days after snowmelt in their trials) vegetation had maximum opportunity to develop and therefore, be better able to resist environmental hazards.

Fall seeding was found to give best establishment results (Brown and Chambers 1989). Chambers et al. (1987b) found that wet cold stratification during winter resulted in fewer days for germination, and therefore, greater likelihood of seedling establishment.

On linear developments such as highway construction, fall seeding may not be practical. Gregg (1976) reported that on the Vail Pass roadway project, seeding was done within 10 days of a slope being completed to grade. This allowed seed to be placed while the soil was still "moist and fluffy", and mulch to be spread to reduce erosion. However, it had the disadvantage of the risk of early fall frost kill on seed that had just germinated. This method therefore, required provision for spot reseeding.

5.6.5.6 Seeding rates. Basing seeding rates on the number of viable seeds per unit area for each species has a number of advantages over the usual method of weight per unit area (Brown and Chambers 1989):

1. Ensures that potential competition among species will be uniform over the area.
2. Permits success or failure of each species in the mixture to be correctly assessed.

The amount of seed applied for each species may need to be adjusted for different seedlots because of variations in seed viability.

Recommended seeding rates usually range from about 200 to 500 total viable seeds per m^2. On harsh sites seeding rates should be close to the higher rate, whereas more favourable sites should be seeded close to the lower rate. Chambers (1987) found that only about 25% to 80% of the viable seeds applied will germinate and emerge.

When seeding is too heavy the plants are stunted and vulnerable to drought because of overcrowding. It has been recommended that the tops of slopes be seeded at a higher rate and the lower slopes at a lower rate to compensate for the downslope movement of seed which can be significant on slopes greater than 27° (David Walker and Associates Ltd. 1981).

5.6.5.7 Competition and compatibility in seed mixtures. Compatability among species in mixtures can be improved by providing phenological and morphological variety among species, by varying seed rates and dates among species based upon competitive relationships, and by excluding overly competitive species (DePuit 1986).

Use of seed mixtures consisting of species with many different physiological and ecological characteristics improves the chances of stand survival in the event of catastrophic events such as insect infestations, disease, or drought (Brown and Johnston 1979).

Low growth rates and high root:shoot ratios are important attributes of species adapted to low nutrient environments. Including low nutrient-adapted and low growth rate-adapted species in a seed mixture with those that are high nutrient-adapted and high growth rate adapted can help ensure revegetation success (Brown and Chambers 1989). Inclusion of different life-forms in seeding and planting mixtures may increase species and struc-

tural diversity of revegetation communities, and enhance rates of successional development (Chambers et al. 1988).

Brown et al. (1984) found that high seeding rates with a mixture of native grasses and repeated applications of fertilizer on acidic spoil material tended to produce closed plant communities that resisted further successional development and enrichment of species diversity. The use of grasses alone in a revegetation mixture, together with repeated fertilization for several consecutive years, resulted in no significant changes in species diversity of the revegetation community 8 years following seeding. It may be necessary to use moderate seeding and fertilizer rates, and to seed low growth rate species in equal amounts as high growth rate species (Brown and Chambers 1989).

Walker (1982) investigated the extent of competition between an agronomic species (*Festuca rubra* var. Boreal) and five native grasses on a disturbed site at treeline (2300 m A.S.L.) in Banff National Park. The agronomic - native grass mixtures were maintained at three different fertility levels: High-N (100 kg-N/ha/yr), Low-N (25 kg-N/ha/yr) and No-N. After three growing seasons, the dominant species in each treatment was noted as either agronomic (A) or native (N), or mixture expressed as a ratio (A:N).

In the high N treatment none of the native grasses could compete with the agronomic species (Table 26). At the low- or no-fertilizer treatments, *Festuca ovina saximontana*, *Poa interior*, and *Trisetum spicatum* dominated the agronomic species. *Agropyron trachycaulum* could not dominate *Festuca rubra* when seeded in a mixture at any of the three fertility levels tested.

In a greenhouse study, Chambers et al. (1987a) found that an early successional species *(Deschampsia caespitosa)* had greater growth rates at all levels of both N and P tested in comparison to a late successional species *(Geum rossii)*. The authors reasoned that the greater growth response of *D. caespitosa* indicated competitive superiority of this species over a wide range of N and P concentrations. They suggested that to promote establishment of late successional species with low relative growth rates in mixed communities, it is necessary to decrease seeding densities of all species or to increase the relative seeding density of species with low relative growth rates.

Table 26. Final composition of plots seeded with an agronomic species (A) and native species (N) at three fertility levels after 36 months.

Native species	High-N	Low-N	No-N
Agropyron trachycaulum Revenue	A	A	A
Festuca ovina saximontana	A	N	N
Phleum alpinum	A	1:1	1:1
Poa interior	A	N	N
Trisetum spicatum	A	1:1	N

Source: Walker (1982)

Chambers (1989b) investigated the influence of seeding density and fertilization on the establishment and growth of native grasses, forbs, and shrubs. The study site was an oil drilling pad located on the north slope of the Uintah Mountains, northeastern Utah at 2743 m A.S.L. Soil on the site is a sandy loam. The seeding density treatment consisted of a constant density of natives (215 m^2) seeded with either: (1) no introduced grasses; (2) an equivalent density of introduced grasses (215/m^2); or (3) three times the density of introduced grasses (645/m^2). Fertilization treatments were: (1) nonfertilized and (2) 56 kg-N/ha as NH_4NO_3, 56 kg-P/ha as P_2O_5, and 28 kg-K/ha as K_2O.

Chambers found that neither seeding density of introduced grasses nor fertilization had any significant effects on the combined seedling density of introduced grasses, native species, and colonizers during the first growing season. A perched water table may have had a negative effect on seedling establishment and favoured invasion by colonizers adapted to moist soil conditions. The colonizers had significantly higher densities than either the introduced grasses or native species ($p<0.05$). When the colonizer species were deleted from the results, there was a significant difference among the three seeding densities and between the introduced grasses and native species.

However, fertilizer additions produced no significant differences in seedling density.

In contrast to the density results, introduced grass standing crop biomass increased with each increase in grass seeding density. Native species showed no differences in standing crop among the three seeding densities. Introduced grasses, native species and colonizers had significantly higher standing crop in fertilized than in unfertilized treatments in year one but by year three there were no differences between fertilized and unfertilized treatments for any of the species categories.

In this study, increasing density of introduced grasses did not lower establishment or growth of the native species. However, because of poor establishment the densities of the introduced grasses and natives may have been insufficient for competition to have occurred. The colonizer species however did exhibit decreases in standing crop with increases in grass seeding density. Introduced grasses, native species, and colonizers all showed large responses to fertilizer. After levels of soil nutrients declined in the fertilized treatments, introduced grasses exhibited a larger relative decrease in standing crop biomass than native species, and colonizers had the largest decrease of all. In the unfertilized treatment, native species had greater increases in standing crop biomass than introduced species. Chambers concluded that native species adapted to low nutrient conditions can maintain more constant productivity on low nutrient soils than the high nutrient-adapted introduced species.

Keigley (1988) had good success with the vegetative propagation of several species for revegetation of road cut slopes in Rocky Mountain National Park, Colorado. Several species of *Carex*, and *Deschampsia caespitosa*, were propagated with nearly 100% success (Table 27). Keigley noted that vegetative propagation eliminates the problems associated with seed collection and germination, and provides a means of producing genetically appropriate plants.

Survival approached 100% when the container grown grasses were transplanted; however, there were some difficulties caused by frost heaving. Some bare root transplants were also tried and most of these survived the first summer.

Table 27. Propagation of native plant species for use in Rocky Mountain National Park. Perlite was the rooting medium, except where noted.

Species	Propagation Method	Degree of Success
Achillea lanulasa	Division[a]	high
Anaphalis margaritacea	Stem cuttings[b]	high
Antennaria rosea	Division[a]	high
Antennaria parvifolia	Division[a]	high
Arctostaphylos uva-ursi	Stem cuttings [b c]	high
Artemisia arctica	Crown division[a]	high
Artemisia borealis	Crown division[a]	high
Artemisia ludoviciana	Division[a]	high
Carex nova	Division	high
Carex misandra	Division	high
Carex scopulorum	Division	high
Deschampsia caespitosa	Division	high
Juniperus communis	Cuttings	none
Linnaea borealis	Cuttings	high
Moss species	Fragmentation[de]	high
Pedicularis racemosa	Cuttings	high
Peltigera apthosa	Fragmentation[d]	none
Penstemon wippleanus	Division, cuttings[b]	none
Polemonium delicatum	Division	high
Salix spp.	Cuttings[b]	low
Sambucus racemosa	Cuttings (0.1% IBA)	high
Rosa woodsii	Cuttings	low
Sedum lanceolatum	Cuttings[b]	high
Selaginella densa	Division	high
Shepherdia canadensis	Division[e]	high
Solidago spathulata	Cuttings[b]	low
Vaccinium myrtillus	Division[b]	high
Vaccinium myrtillus	Cuttings	little

[a] Rooted in peat-based potting mix.
[b] Treated in 0.3% IBA (Hormodin #2).
[c] Early season cuttings were substantially more successful.
[d] Mosses and lichens were fragmented using a blender run at low speed.
[e] IBA treatment (at any level) inhibited growth.

Source: Keigley (1988)

5.6.5.8 Mulches to aid seedling establishment. Many alpine sites are windy and subject to late summer drought. Needle-ice formation also occurs in bare alpine soils which are subjected to freezing temperatures and which have some soil moisture. The columns of ice which form, cause disruption of the soil and of vegetative growth. Needle-ice can perpetuate these bare areas and even expand them. Brink (1964) noted that under a snow patch freezing does not extend into the soil where there is heath vegetation, but it does when the soil is bare. Thawing of this frozen layer results in water saturation at the surface. This causes surficial flow or shallow solifluction of the saturated soil over the sloping frozen soils beneath the surface.

Mulches may assist plant establishment on disturbed alpine sites because they can retard evaporation, ameliorate high surface temperatures, and reduce the incidence of severe frost action. They can also hold seed and fertilizer in place and prevent soil crusting.

Van Kekerix et al. (1979) found that the incorporation of peat moss and the use of jute netting significantly improved seedling growth, survival, and water relations of two grass species on acid mine spoil at Beartooth Plateau, southern Montana.

Davy (1953) conducted greenhouse studies on the effectiveness of sawdust compost on plant growth. His studies demonstrated that fresh sawdust applications of 25 m^3/ha strongly depressed the growth of coniferous and deciduous tree seedlings, and green manure crops. Sawdust treated with anhydrous ammonia, phosphoric acid, and potassium sulphate failed to completely alleviate the adverse influence of sawdust and required additional treatment of plants with nitrogen fertilizers. The C/N ratio of treated sawdust was decreased by inoculations with *Coprinus ephemerus*. This organism was efficient in decomposition of cellulose, and within 3 months, converted sawdust into finely divided dark brown compost. Application of composted sawdust to sandy soil produced marked increases in the growth of both coniferous and deciduous seedlings, and red clover.

Hassell (1982) described mulch treatments used in a program to revegetate 50 ha of mine tailings at 2910 m A.S.L. near Silverton, Colorado. The tailings were covered with 21 m of waste rock on the surface and 3 m on the dam faces. Eighteen tonnes of wood chips and 27 tonnes of sewage sludge were mixed into the rock surface with a bulldozer. The amended tailings were

seeded with grasses and irrigated during the first growing season. Tree seedlings and shrubs planted in the second growing season had a 50% to 60% survival rate.

Walker and Harrison (1986) have used mulches to facilitate revegetation of worn hiking trails at Whistlers Mountain, Jasper National Park (2256 to 2465 m A.S.L.) and Parker Ridge (2035 to 2271 m A.S.L.), Banff National Park. A roll out rice-paper mulch was used on wet or exposed sites. On these sites cold soil temperatures were considered a limiting factor for plant growth. The mulch can increase soil temperature by preventing heat loss through advection and by creating a 'greenhouse effect'. Walker and Harrison noted that to be effective the mulch must be carefully installed with the fabric laid as close to the soil surface as possible. A layer of air between the fabric and the soil becomes a layer of insulation which will lower the soil temperature. The fabric must also be properly secured. Excessive movement of the fabric will quickly destroy any seedlings which protrude through the weave of the paper strips.

A roll out Excelsior (aspen wood) mulch was used on wind swept ridges and slopes with a southerly exposure on Whistlers Mountain. On these sites soil moisture is limiting to plant growth. The technique was considered to be successful in aiding plant establishment. They noted that one of the benefits of using mulches is that they are highly visible and can alert hikers that sites are being revegetated. The Excelsior mulch eventually had to be removed from the site however, since it did not decompose (pers. comm. Gail Harrison, Canadian Parks Service).

Urbanska (1988) found that biodegradable mats (Curlex) improved seedling emergence and survival on disturbed sites in the Swiss Alps. The study area was located on machine-graded ski runs and talus slopes at about 2400 m A.S.L. Soil were derived from dolomite. Each 1 m^2 plot was seeded with a mixture containing about 1000 seeds. Some plots were covered with Curlex matting while other plots were left uncovered. The uncovered plots were characterized by a relatively fast seedling turnover, whereas the covered plots showed a slowly increasing seedling emergence with better survival of young plants (Table 28).

Table 28. Number of plants in various plots seeded in early summer 1984. Census of August 1987.

Plot	Ski Run Unprotected	Ski Run Curlex	Scree Unprotected	Scree Curlex
No. of plants[a]	145	250	205	283

[a] immigrant plants included
Source: Urbanska (1988)

Urbanska also found a marked increase in the number of invading species in the Curlex covered plots in contrast to the uncovered plots. No invading species were noted on the unprotected ski run plots.

Thomson and Sembenelli (1987) found that jute mesh greatly enhanced vegetation establishment on a steep alpine slope at 1995 m A.S.L. in the western Italian Alps. The test site was located on actively eroded south-facing 27° slopes. Soils are silty sands with 30% coarse fragment content. The seed mix used contained 25% *Lolium perenne*, 24% *Festuca ovina*, 20% *Poa pratensis*, 21% *Trifolium pratensis*, and 10% *Trifolium hybridum*. The seed was applied over the jute netting at a rate of 10 g/m^2 without fertilizer. The revegetation process was monitored by observation and photographic record. After 1 year the vegetation cover on the jute strip was dense and uniform in contrast to the control strip which was completely bare of vegetation. Biodegradation of the jute was tested after 175 days and 147 days of winter and summer exposure, respectively, in high altitudes. A tensile test and soaking test were conducted. Decay of mechanical characteristics of the netting amounted to 60% per year. Water retention capabilities were reduced by 20% per year. The authors noted that the entrapment of fines by the jute promoted germination and growth of the vegetation. The jute also tended to absorb and store rainwater and night dew with delayed slow release during the day. They considered that although jute is more expensive than straw mulching it was more effective on slopes greater than 20%.

Hendzel (1976) found that placement of brush, treetops, and logs over grass/legume plantings was beneficial in stand establishment. The recontoured drilling sites were located in the lower alpine (2743 to 2896 m A.S.L.) in the Absaroka Range, southeastern Montana. He suggested that mulch treatment reduced the high intensity sunlight and wind-caused desiccation, and allowed snow to accumulate on this wind-swept tundra site.

Sadasivaiah and Weijer (1982) investigated the influence of a peat mulch on seedling establishment at a disturbed alpine site (2290 m A.S.L.) on Whitehorn Mountain near Lake Louise. The soils are low in N and P, and are developed in coarse-textured glacial till with a high coarse fragment content. The site has an easterly aspect with slopes ranging from 10° to 30°. A light covering of peat moss (unspecified depth) was applied to seeded grass plots to determine if seedling establishment could be improved by this treatment. The peat moss was found not to have a significant influence on the establishment of the native grasses tested. The authors noted that there was some evidence that some of the grasses reacted adversely to mulching. They concluded that mulching at time of seeding was not required. However, there was a possibility that the peat mulch may have "slid off" on this steep site or was blown away before it could become effective.

Walker (1982) found that the presence of a peat mulch had no effect on rates of seedling establishment after one growing season, although emergence tended to be delayed on the mulched plots. The site was located at treeline (2300 m A.S.L.) on an east-facing 25° slope at the Lake Louise ski area. The plots were planted as paired plots in three replications. The mulch treatment consisted of peat moss applied to a depth of 1.3 cm. After 3 years, plant growth on mulched plots was very poor in comparison to unmulched plots; only seven of the 18 species planted remained in the mulched plots. These included: *Deschampsia caespitosa*, *Poa interior*, *Festuca ovina saximontana*, *Poa alpina*, *Agrostis scabra*, *Trisetum spicatum*, and *Festuca rubra* var. Boreal. Walker suggested that the mulch acted as an insulating layer that kept soil temperatures low.

Berg et al. (1986) investigated mulching treatments at two sites at the Climax Mine, Colorado. The two sites were a silty clay loam subsoil 130 m above treeline, and a mine rock waste 330 m above treeline. The subsoil site was on a west-facing, 6% slope. Sod and topsoil to a depth of 20 to 25 cm was

removed to expose the subsoil. The subsoil was low in plant-available N, P, and K. The rock waste site was a level bench bordered on the south and east by steep slopes. Soil size material is a sandy loam which tested low in organic matter and plant-available N, but adequate in P and K.

Five mulching treatments were applied to the subsoil site after seeding in October 1978:

1. 4.4 Mg/ha wheat straw held in place with plastic netting;
2. Jute;
3. Excelsior erosion blanket;
4. 44 Mg/ha softwood wood chips; and,
5. Simulation of a straw mulch held in place with a tackifier.

Rock waste mulch treatments were the same as the subsoil treatments, except for treatment five where 7.5 cm of cover soil taken from a topsoil stockpile was applied to the rock waste in place of a mulch treatment.

After the first growing season more plants were found on plots mulched with excelsior than on plots mulched with other materials. However, after two growing seasons this effect was not found. After the second growing season, jute, Excelsior and woodchip mulches showed little degradation, whereas ground cover by straw was reduced to 75% from 90%.

Seven years after application, the only mulch material remaining on both the rock pile site and subsoil sites was the plastic net used to hold the straw in place. On the subsoil site there was no significant difference in the amount of vegetation cover produced by the different mulch types (straw, jute, Excelsior, woodchips). On the rock pile site, vegetation cover was also similar among the mulches. All mulches produced similar cover to the no mulch treatment except jute, which produced significantly higher cover than the no mulch treatment. However, the researchers concluded that straw plus net, jute or Excelsior performed equally well in this trial and that the need for mulches on the rock waste site was not conclusively shown.

Brown and Johnston (1978) investigated the influence of straw mulch on transplant growth and development on the Beartooth Plateau, Montana. Native and introduced transplant plugs, grown from seed collected the previous year, were allowed to harden off on the site for 3 weeks prior to planting in September 1976. A total of 5300 grass plugs were transplanted. One half of the transplant area was mulched with a straw mulch at a rate of 2500 kg/ha.

The straw was tacked down with a water soluble asphalt emulsion and blown onto the site with a power mulcher.

Straw mulch application had a negative effect on the basal diameter and height growth for all species, and a depressing effect on flower development for nearly all species. Growth of the native species was affected less than the introduced species (Table 29). Eighty percent of all mortality of the transplants occurred on the mulched portion of the plot. Brown and Johnston attributed the poor performance of transplants on the mulched areas to maintenance of suboptimum temperatures for growth near the soil surface. It was observed that mid-summer snows tended to linger longer on the mulch surface than on the untreated spoil piles. However, the straw mulch did reduce the incidence of needle-ice which was observed frequently on the unmulched areas but not in the mulched area.

5.6.6 Alpine Shrubs

Walker and Harrison (1986) reported that *Dryas octopetala* (white mountain avens) and *Arctostaphylos rubra* (alpine bearberry) can be readily propagated by seed. *Silene acaulis* (moss campion), *Phyllodoce glanduliflora* (yellow mountain-heath), *P. empetriformis* (purple mountain-heath), *Antennaria lanata* (wooly everlasting), *Saxifrage oppositifolia* (purple saxifrage), and *Sedum laceolatum* (stonecrop) can be propagated from softwood cuttings. This technique involves collecting specimens of parent plants that are small and young, and placing them in small pots in a growth chamber. The plants are then maintained at 18 to 22°C for an extended growing season (6 to 8 months) with frequent applications of fertilizer. Softwood cuttings are then taken from the resultant tall and lank growth. The plants resulting from these cuttings are grown at a much slower rate to encourage a natural growth habit, and thoroughly hardened off prior to transplanting (Walker and Harrison 1986).

5.6.7 Transplanting Individual Plants

Brown and Johnston (1976) found that native plants of *Antennaria lanata*, *Carex paysonis*, *C. nigricans*, *Deschampsia caespitosa*, and *Poa alpina* all survived 1 year after transplanting in acid mine spoil. The study site was located at the McLaren Mine, Beartooth Plateau, Montana. The selected native plants had extensive root systems and crown development, and were

Table 29. Influence of straw mulch application on transplant growth and development on the McLaren Mine, Beartooth Plateau, Montana. The average basal diameter for all species at the time of planting was 2 cm.

Species	Mulch			No Mulch		
	Basal diameter (cm)	Plant height (cm)	Flower (%)	Basal diameter (cm)	Plant height (cm)	Flower (%)
NATIVES						
A. trachycaulum	1.5	12.0	0	2.1	19.3	37
Deschampsia caespitosa	2.7	8.9	0	4.4	9.4	0
Phleum alpinum	3.9	14.6	9	4.6	26.2	76
Poa alpina	4.0	7.6	0	4.8	14.7	4
Trisetum spicatum	1.5	6.0	0	4.0	6.5	0
Average	2.7	9.8	2	3.9	17.4	31
INTRODUCED						
Alopecurus pratensis	2.3	18.8	25	2.8	19.9	43
Bromus inermis	1.1	12.4	0	1.9	22.0	60
Dactylis glomerata	0.6	8.5	0	1.2	11.7	0
Festuca arundinacea	0.5	9.0	0	1.9	22.6	40
Phleum pratense	1.2	14.6	20	2.2	19.5	30
Poa compressa	5.2	33.0	100	6.0	34.0	100
Average	1.8	16.1	24	2.7	21.6	46
Average All Species	2.2	13.2	14	3.3	18.7	39

Source: Brown and Johnston (1978)

collected from road cuts near the mine. The authors noted that germinating seedlings are more sensitive than mature plants to periods of severe desiccation and frost heaving. The use of transplants may, therefore, more readily ensure plant establishment and development on alpine disturbances. However, a fairly large percentage of the soil surface will remain bare and subject to erosion until lateral growth of the transplants extends into the open spaces. At present, little is known about the rate of lateral spread by transplants.

May et al. (1982) investigated the rate of transplanting success of six native alpine plant species within and among seven microenvironments on Niwot Ridge, Colorado. The seven microenvironments (fell-field, dry meadow, shrub tundra, moist meadow, wet meadow, early snowbed, and late snowbed) were characterized according to soil moisture, mean annual snow depth, length of growing season, above-ground and below-ground temperatures, and frequency and abundance of plant species.

Transplanting was done in June and July 1973 by carefully excavating the root system and removing soil from the roots prior to replanting. Transplants were watered for several weeks to minimize early mortality. They were considered to be successfully established if vegetative growth occurred in the growing season after that of transplanting.

Transplanting success was greatest for *Deschampsia caespitosa* (98%, n = 280), followed by *Kobresia myosuroides* (83%, n = 70), *Acomastylis rossii* (79%, n = 490), *Carex pyrenaica* (70%, n = 70), *Sibbaldia procumbens* (44%, n = 140), and *Carex rupestris* (17%, n = 140). Success was not uniform among all noda and varied for all transplants between 83% (wet meadow) and 44% (fell-field) (Table 30). There was also considerable variation in the transplanting success of individual species among the noda. *Deschampsia caespitosa* was transplanted successfully to all noda while *Carex rupestris* was transplanted with moderate success to only the dry meadow. *Carex pyrenaica* had poor transplant success in the fell-field and the late snowbed.

Several factors influenced transplant success:

1. Nature of the microenvironment. Except for *Deschampsia caespitosa*, all species had lower success in the fellfield which is rocky, dry, windy, and has extreme fluctuations in temperature. For example, *Acomastylis rossii* had transplanting success of

Table 30. Success of transplants (percent) according to relocation site from the longest (fellfield) to the shortest (snowbed) growing season. Plant species are in order of frequency of occurrence in thirty sampled stands from greatest (*Acomastylis rossii)* to least (*Carex pyrenaica)*

Transplanted plant species		Fellfield	Dry meadow	Shrub tundra	Moist meadow	Wet meadow	Early snowbed	Late snowbed
Acomastylis rossii (R.Br.) Greene	(n=70)	46[a]	81[a]	87[a]	81[a]	93[a]	83[a]	80[a]
Deschampsia caespitosa (l.) Beauv.	(n=40)	90	95	100[a]	100[a]	100[a]	100	100[a]
Carex rupestris Bell. ex. All.	(n=20)	15[a]	60[a]	0	20	15	0	10
Sibbaldia procumbens L.	(n=20)	5	0	65	80	65	55[a]	40[a]
Kobresia myosuroides (Vill.) Fiori & Paol.	(n=10)	30	90[a]	100	90	100	90	80
Carex pyrenaica (Wahl.)	(n=10)	0	80	90	100	100	80[a]	40
Total	(n=170)	44	73	78	80	83	74	69

[a] Ten individuals were transplanted within this noda and from this noda to all other noda.
Source: May et al. (1982)

46% in the fellfield, but success varied between 80% (late snowbed) to 93% (wet meadow) for the other noda. Differences in microclimate need to be closely observed and matched with vegetation patterns to indicate the proper species for transplanting to given sites (Willard 1976).

2. Nature of plant root systems. Monocotyledons and herbaceous dicotyledons with shallow, fibrous roots, and rootstocks had low transplanting success. However, monocotyledons with fibrous roots but no rhizomes or other rootstocks which can be broken during transplanting, had good transplanting success. One exception to this was *Acomastylis rossii* which has along tap root which was always broken during transplanting, but it also has an extensive system of secondary roots which apparently permitted high transplant success.

The authors concluded that the best prospects for use of sod clumps would be from homogeneous stands of either *Kobresia myosuroides* in the dry meadow or *Deschampsia caespitosa* in the wet meadow. Both these sites are protected by winter cover and would revegetate naturally.

Webber and Ives (1978) reported some success with cloning grasses in the greenhouse for planting in the alpine zone of Colorado. They also had success transplanting mature plants from one location to another. Transplanting success was strongly related to root form - plants with fibrous roots did better than plants with rhizomatous roots, and these did better than those with rootstocks or corms (May 1976). Transplant success was also strongly related to the potential tolerance range of a species, so that naturally wide ranging species tended to be the best transplanters.

Several alpine shrub species have been successfully transplanted as part of hiking trail rehabilitation on Whistlers Mountain, Jasper National Park (2256 to 2465 m A.S.L.). Approximately 2000 transplants were planted by auger after snowmelt in early July. Survival after 2 years is given in Table 31.

Table 31. Survival of alpine shrubs transplanted at Whistlers Mountain Trail, Jasper National Park.

Species	Survival after 2 years (%)
Salix nivalis	44.1
Salix arctica	70.2
Silene acaulis	90.6
Sedum lanceolatum	69.8

Source: Walker and Harrison (1986)

Willey (1982) examined the growth responses of five native species on simulated mine spoils. Mature plants were collected in the upper reaches of the subalpine and portions of the alpine zone in northeastern British Columbia. The plants tested were: *Salix arctica, Dryas integrifolia, Hedysarum alpinum, Oxytropis sericea*, and *Oxytropis podocarpa*.

An equal number of plant specimens were grown in pots of crushed shale (simulated mine spoil) and in mineral soil. No fertilizer was added to either growth medium. Plants were grown at the University of British Columbia, Vancouver. After a specified growth period, above-ground biomass was clipped, oven-dried, and weighed. Willey found that *Salix arctica, Hedysarum alpinum*, and *Oxytropis sericea* grew equally well on the shale and mineral soil. *Oxytropis podocarpa* was less successfully transplanted. This species has a large tap root which may have contributed to the lower survival rates. Willey (1982) recommended that *Dryas* spp. should not be planted on unweathered shale.

Brown and Johnston (1978) transplanted native and introduced grass species grown in plastic tubes on mine spoil in the subalpine-alpine transition zone in the Beartooth Mountains, Montana. Plants were grown from seed collected the previous year. The plugs were allowed to harden off on the site for about 3 weeks prior to planting in September. The mine soil had been limed (2200 kg/ha) to increase pH to about 5.0, and manure was applied at a rate of 2200 kg/ha. The site was also heavily fertilized with 18-46-5 (with 0.8% zinc) at a rate of 672 kg/ha.

The native species had a first year survival of 75%, whereas the introduced species had a survival rate of only 39% (Table 32). Although *Trisetum spicatum* had the lowest survival of the native species, growth of surviving plants was substantial. Although only eight plants of *Agropyron scribneri* were planted, all plants survived, and flowered. Among the introduced species *Alopecurus pratensis, Phleum pratense*, and *Poa compressa* showed encouraging results.

Urbanska (1986) considered that direct transplanting should be avoided because of the damage caused to the area used as a source of plants. However, she found that tussocks of some alpine grasses can be easily subdivided into single tillers. For example, a small tussock (about 15 cm in diameter) of *Festuca pumila* consists of about 300 tillers. These could be

Table 32. Summary of first year results of transplant survival and production on the McLaren Mine site, Montana.

Species	Survival (%)	Ave. dry wt. per plant (gm)	No. Planted 1976	No. Live 1977
NATIVES				
Agropyron scribneri	100	2.0	8	8
A. trachycaulum	83	1.4	124	103
Deschampsia caespitosa	72	2.4	993	711
Phleum alpinum	73	3.5	1016	739
Poa alpina	80	3.7	1682	1351
Trisetum spicatum	24	0.9	86	21
Average/Total	75	2.3	3909	2933
INTRODUCED				
Alopecurus pratensis	72	0.9	349	253
Bromus inermis	29	1.3	272	78
Dactylis glomerata	7	1.1	270	20
Festuca arundinacea	24	0.5	245	59
Phleum pratense	40	1.1	248	100
Poa compressa	91	6.5	70	64
Total/Average	39	1.9	1454	574
Average All Species/Total	65	2.1	5363	3507

Source: Brown and Johnston (1978)

separated into individual tillers. Urbanska found that 300 tillers were sufficient to revegetate an area about 16 m^2 and about 95% to 100% of the transplants survived. The recovery time from a single tiller to a developed clonal module of several tillers was 6 weeks to 2 months. This cloning process also tended to promote vegetative growth and for some species, it also stimulated the formation of reproductive structures. Urbanska (1986) noted that fragmentation of clones may occur naturally, and most frequently on unstable or disturbed sites.

Walker et al. (1977) presented data for a large transplant study in the Rocky Mountains of Alberta. A list of grasses used in this study is given in Table 33. Seeds were germinated in growth chambers, transplanted to containers, and planted in mountain test sites in July. Sixteen plants of each species were planted 25 cm apart in a one square metre plot. The containers were planted directly into unamended soil or spoil materials.

Results for upper subalpine and alpine sites in this study are presented in Table 34. No statistically significant interactions between species and sites were observed. Survival at all sites was high which suggests that seedling establishment is the most critical limitation for successful use of native species for revegetation. The authors noted that transplanting container grown grass seedlings (at least three to four tiller stage) would be an effective method of obtaining immediate cover on disturbed high altitude sites.

5.6.8 Transplanting Sod

Transplanting sod or turf is a suitable revegetation technique in the alpine because of the short growing season. It enables plants to become quickly established. Turf provides an intact, compact erosion controlling ‘cover’ with organic matter and microorganisms ‘built in’. Alpine turf is resistant to transplanting provided it is kept upright and moist (Willard 1976).

Transplanting trials were undertaken on the Beartooth Plateau at Iron Mountain (3077 m), McLaren Mine (2990 m), and Goose Lake (2995 m) in southern Montana (Brown et al. 1976). Turf pieces from road cuts were used. In some locations on Iron Mountain, the seed produced by the transplants produced an abundance of young seedlings on the lee sides of the plants, and

Table 33. Grasses used in transplant studies in the Rocky Mountains of Alberta.

Genus and Species	Source	Elevation (m A.S.L.)
1975 Establishments		
Agropyron dasystachyum	Exshaw	1372
Deschampsia caespitosa	Whitehorn Mtn.	1829
Stipa columbiana	Pigeon Mtn.	1676
Trisetum spicatum	Mt. Rae	2286
Poa alpina	Mt. Rae	2286
Poa arctica	Whistlers Mtn.	2347
1976 Establishments		
Agropyron dasystachyum	Provincial wide selection	NA
Agropyron latiglume	Peyto Lake	2195
Agropyron trachycaulum	Banff Flats	1372
Agropyron subsecundum	Kootenay Plains	1372
Bromus pumpellianus	Provincial wide selection	NA
Festuca saximontana	Caw Creek Ridge	1981
Koeleria cristata	Provincial wide selection	NA
Phleum alpinum	Peyto Lake	2195
Poa alpina	Whitehorn Mtn.	1829
Poa arctica	Whistlers Mtn.	2347
Stipa columbiana	Pigeon Mtn.	1676
Trisetum spicatum	Mtn. Park Pass	2042

NA - Not applicable.

Source: Walker et al. (1977).

Table 34. Percentage of plants surviving and producing seed heads after transplanting at various sites in the Alberta Rocky Mountains.

Site	Elevation (m A.S.L.)	No. of Plants	Survivors July, 1977 (%)	Reproducers July, 1977 (%)
1975 Establishments				
Caw Creek Ridge near Grand Cache	1981	128	68	58
Highwood Pass near Canmore	2206	96	85	59
1976 Establishments				
Caw Creek Ridge near Grande Cache	1981	160	99	11
Prospect coal mine near Hinton	2042	160	69	12
Snow Creek Pass Roadside near Banff	2200	160	81	22
Tent Mountain coal mine near Coleman	2134	158	87	30

Source: Walker et al. (1977).

many of these have become well established. The transplants were found to be capable of seed production after only one growing season.

Native species successfully transplanted included the grasses: *Deschampsia caespitosa*, *Alopecurus pratensis*, *Poa alpina*, *Phleum pratense*, *Phleum alpinum*, *Dactylis glomerata*, *Trisetum spicatum*, *Carex paysonis*, *Agropyron intermedium*, *Agropyron scribneri*, *Poa pratensis*, *Agropyron trachycaulum*, and *Festuca arundinacea*. The following forbs were also successfully transplanted: *Antennaria lanata*, *Lupinus argenteus*, *Sibbaldia procumbens*, and *Phyllodoce empetriformis*.

Researchers noted that on the basis of plant survival per individual planted, transplanting was the most successful revegetation technique used on these sites. Only about 10% to 30% of native seed is usually viable, and

only a small proportion of these ultimately survive to the adult stage of development. Based on their seeding research, about 3 years are required for seeded plants to produce seed heads. Transplants are usually capable of seed production after only one growing season. They considered transplanting was successful because:

1. Plants are dormant when transplanted so physiological damage is reduced.
2. The well developed root systems and root crowns are less susceptible to desiccation and frost heaving than young emerging seedlings.

Walker (1982) described transplant trials undertaken at the Lake Louise ski area (1670 to 2840 m A.S.L.) using selected native and agronomic species. The trial site was located at tree-line on a 25° (average) east-facing slope. Soils were well-drained, sandy-clay, slightly alkaline, and barren of vegetation. Soil nutrients, particularly nitrogen and phosphorous, were extremely low.

The transplant trials used single plants that had been grown for the previous 3 months in Spencer-Lemaire root trainers. The plots consisted of 16 transplants/m^2 for each species in three replications. Survival rates of transplanted species after 36 months are given in Table 35.

Survival of the best performing 11 species in Table 35 remained static over the 3 years of observation. All other species exhibited a definite decline in survival with the exception of *Trisetum spicatum*. Species commonly found in alpine areas exhibited superior survival. *Festuca rubra rubra* (Boreal) and *Agropyron trachycaulum* (Revenue) both demonstrated good winter hardiness, but neither variety set seed. Natives which set seed, reseeded, and invaded other plots were: *Poa interior*, *Poa cusickii*, *Deschampsia caespitosa*, and *Festuca ovina* spp. *saximontana*.

Of the agronomic species tested, *Phleum bertolonii* var. Evergreen and *Poa ampla* Sherman had poor survival. *Poa pratensis* var. Banff demonstrated good performance at high elevations. Walker suggested this variety may be substituted for the Alaskan variety Nugget. *Medicago sativa/falcata* var. Anik, a variety developed in northern Alberta, also performed well at this elevation.

Table 35. Survival (percent) of species transplanted to a disturbed alpine site after 36 months.

Name			Average 3 Reps
Deschampsia caespitosa		Tufted hairgrass	100
Poa alpina		Alpine bluegrass	94
Poa interior		Interior bluegrass	90
Festuca ovina saximontana		Alpine fescue	84
Agropyron latiglume		Alpine wheatgrass	83
Festuca rubra rubra	Boreal	Creeping red fescue	79
Agrostis scabra		Rough ticklegrass	78
Poa cusickii		Cusick's bluegrass	78
Calamagrostis purpurescens		Purple reedgrass	75
Agropyron trachycaulum	Revenue	Slender wheatgrass	75
Agropyron trachycaulum		Slender wheatgrass	67
Koeleria cristata		June grass	67
Agropyron subsecundum		Bearded wheatgrass	59
Agropyron dasystachyum		Northern wheatgrass	58
Phleum alpinum		Alpine timothy	56
Trisetum spicatum		Spike trisetum	53
Stipa columbiana		Columbia needlegrass	0
Agropyron spicatum		Bluebunch wheatgrass	0
Agropyron cristatum	Parkway	Crested wheatgrass	0
Additional check varieties after 16 months			
Poa pratensis	Banff	Kentucky bluegrass	97
Festuca rubra rubra	Boreal	Creeping red fescue	92
Festuca ovina duriuscula	Burar	Hard sheep fescue	89
Medicago sativa/falcata	Anik	Alfalfa	89
Poa compressa	Reubens	Canada bluegrass	81
Poa pratensis	Nugget	Kentucky bluegrass	81
Festuca rubra rubra	Reptans	Creeping red fescue	71
Alopecurus pratensis		Meadow foxtail	63
Phleum bertolonii	Evergreen	Diploid timothy	56
Poa ampla	Sherman	Big bluegrass	50

Source: Walker (1982)

Marr et al. (1974) used the technique of stripping and replacing sod to reclaim a pipeline in the alpine tundra, Rollins Pass area, western Colorado. The sod was "peeled off" using a rubber tired backhoe and placed on a sheet of plastic beside the ditchline. The sod was covered with burlap to reduce loss of water from the soil and plants. The sod was subsequently replaced after the trench was backfilled. Permanent transects were established at 5 m intervals along the 500 m length of pipeline to record changes to the disturbed tundra and undisturbed tundra on either side of the ditchline.

Their main findings were:

1. *Deschampsia caespitosa*, the dominant species in the climax vegetation type, tolerated the sodding operation with little change in its own stand type, and invaded other stand types.
2. *Geum rossii*, *Vaccinium scoparium*, and *Sibbaldia procumbens* were much reduced in cover in all stand types.
3. All stand types lost some species.
4. *Viola bellidifolia*, *Thlaspi montanum*, *Ranunculus adoreus*, *Poa glauca, and Carex ebenea* increased adjacent to the trenchline but decreased on top of it, while *Minuartia obtusiloba*, *Bistorta bistortoides*, and *Deschampsia caespitosa* reacted in the opposite way.
5. When sod was replaced below the adjacent ground level, plants were buried by soil washed into the depressions. If placed above the adjacent ground level the edges of the replaced sod dried out and wind erosion inhibited revegetation.

Walker and Harrison (1986) found that salvage and transplanting of alpine vegetation sod was a successful method of rehabilitating alpine hiking trails. They noted that care must be taken to match habitats when moving sod even short distances along a moisture gradient or from a snowbed to an exposed location. Prompt replacement of the sod to the new location was also necessary for good results. If stored for more than about 1 week, the edges of the sod pieces may dry out to the extent that the vegetation will not recover. They noted that burlap fabric which provides shading and allows some air movement is better for preserving sod moisture than clear plastic sheeting which may cause high temperatures to develop.

5.6.9 Equipment

The following section describes equipment that was primarily developed by the Missoula Equipment Development Centre, USDA Forest Service in Montana, for use in revegetating arid and semiarid lands. Some applications of this equipment may be useful for revegetating alpine areas.

A dryland plug planter is a machine which plants containerized tree and shrub stock up to 61 cm long. The planter is tractor-mounted and contains levelling devices to enable operation on rough ground or moderate slopes. Planting rates are estimated at more than one seedling per minute (Hallman 1982).

A similar tree/shrub planter was developed at the San Dimas Equipment Development Centre. Tests showed that on slopes of 1:1 and dry soils, the augered holes filled up with dirt before the shrub could be planted. It was recommended that this planter not be used on steep slopes unless they have been stabilized with grass (Pickett 1974).

Moden and McKenzie (1983) described a planter attachment which was reported to increase planting rates, reduce damage to slopes by hand-planters, and reduce labour needs and costs. This planter attachment was designed for use on a standard backhoe. Field trials indicated that this planter was 2.8 times as efficient as mechanical hand planting.

Hallman (1982) described a specialized sodder which strips the top layer of soil and vegetation from undisturbed areas and places it intact over reshaped disturbed areas. The advantage of using a sodder is that soil horizons are not mixed. Shallow soil typical of alpine areas may exclude its use.

Another planting device described by Hallman (1982) was a sprigger that harvests reproductive rhizomatous stems, sprigs, or portions of rhizomatous stems capable of producing roots and shoots. It does this by undercutting, gathering, and subsequently spreading them on the area to be revegetated and covering them with soil. The sprigger was 1.5 m wide and was towed by a tractor.

A steep slope seeder was developed at the San Dimas Equipment Development Centre in California, that can simultaneously scarify, seed, and fertilize steep slopes (Adolphson et al. 1982). The seeder was designed to be attached to the telescoping boom of a hydraulic crane or towed by a small tractor on moderate slopes. Test results indicated the seeder performed well

on slopes of 0.75:1 that were littered with rocks, stumps, and limbs. The seeder appeared well adapted to a wide range of soil types and conditions. It was capable of seeding approximately 1 ha/hour.

5.7 SOIL FERTILITY AND FERTILIZATION

5.7.1 Soil Fertility

It has long been recognized that alpine soils are rather poorly developed and generally have a low nutrient availability, some nutrients being limiting (Knapik 1973; Retzer 1974). This contrasts with the subalpine where soil development is usually advanced and soil nutrient content can be high (Knapik 1973; Retzer 1974; Urbanska and Schutz 1986).

Analyses of alpine soils sampled from Lookout Mountain and Phillips Pass, Banff National Park, Alberta are given in Table 36. These soils are low in nitrogen, phosphorus, and potassium. The levels of N are approximately 10% that of a prairie agricultural soil. The P and K levels are also in a range considered extremely deficient for agronomic plant growth.

Table 36. Various chemical parameters of some alpine soils.

Sample	pH	EC ($mScm^{-1}$)	Nitrogen (ppm) NO_3/NO_2	Nitrogen (ppm) NH_4	P (ppm)	K (ppm)	OM (%)
Lookout Mountain (July 1987)	7.8	0.16	0.5	6.5	9.4	12.1	2.7
Lookout Mountain (Aug. 1987)	7.8	0.12	0.5	6.6	9.5	7.0	2.6
Lookout Mountain (Aug. 1988)	7.8	0.20	0.3	4.6	8.1	4.1	3.2
Phillips Pass (Aug. 1988)	8.0	0.22	5.2	10.8	9.6	16.0	5.7

Source: Acharya et al. (1989)

Haselwandter et al. (1983) found that in alpine ecosystems fluxes in nutrients, especially nitrogen, occur during the growing season. These fluxes may be more important than total pool sizes. However, alpine tundra plants living in a low nutrient environment are well adapted to low nutrient availability and have been selected for growth under such conditions rather than for a large growth response to nutrient availability as is the case for agronomic species (Shaver and Chapin 1980). The life history strategies of alpine plants indicate that their functioning is not impaired by nutrient limitations and other adverse conditions occurring above timberline (Urbanska 1985).

Chambers et al. (1987a) determined the growth response of an early seral dominant alpine grass, *Deschampsia caespitosa*, and a late seral dominant alpine forb, *Geum rossii*, grown in a factorial greenhouse experiment at four levels of nitrogen (N) and four levels of phosphorus (P). They were grown in pots of alpine soils of granitic origin in the greenhouse. Light was supplemented to provide a 14-h day length. Responses of the two species to the levels of N and P were evaluated by measuring final root and shoot weights, N and P concentrations and contents, and by calculating root:shoot (R:S) ratios and relative growth rate (RGR):

$$RGR = (\ln W_t - \ln W_o)/t$$

where: W_o = average dry weight of plants when transplanted in alpine soil

W_t = individual dry weight of plants at end of experiment

t = time of experiment (56 days)

The late seral dominant forb responded like a species from a low nutrient environment, exhibiting a much lower relative growth response (RGR) and generally higher root:shoot ratio than the early seral dominant species. In addition, the early seral dominant species showed a greater response to levels of N, while the late seral dominant species were more sensitive to levels of P.

Chambers et al. (1987b) examined N and P levels from early and late successional alpine sites in the Beartooth Mountains and found that late serals had five to ten times more P than paired early serals, but only one to five times available N (NO_3^- plus NH_4^+).

5.7.2 Soil Microflora

5.7.2.1 Mycorrhizal fungi. Because of low mean annual temperatures, rates of nutrient mineralization in the alpine are likely to be slow and availability of major nutrients like nitrogen and phosphorus may be consequently restricted. Mycorrhizal associations, if present, are therefore likely to benefit alpine plant communities. Chapin (1980) noted that mycorrhizal associations are critical to plant nutrition in infertile habitats. Mycorrhizae provide the greatest benefit to plants in overcoming limitations by nutrients that diffuse slowly in soil (phosphate>>ammonium>>potassium> nitrate).

In a survey of some Austrian alpine plant communities, ectomycorrhizal infection of the vesicular-arbuscular (VA) type was found to be widespread, but there was considerable variation in both the type of infection and its intensity. Such infection is known to have the capacity to enhance plant growth and phosphorus uptake (Sanders et al. 1975). The lowest levels of VA mycorrhizal infection were found in the nival zone above 3000 m A.S.L. and a fertilized hay meadow at 1600 m A.S.L. Higher levels of infection were found in the high altitude, late snow patch communities although these values were still very low. The highest levels of infection were consistently found in the grassland communities above the treeline and below the lower limit of the nival zone. The authors suggest that the low intensities of mycorrhizal infection at high altitudes probably result from low levels of nutrient stress, short periods of root growth, the lack of root contact, and competition (Read and Haselwandter 1981).

Haselwandter and Read (1982) found that the alpine sedges *Carex firma* and *C. sempervirens* had significantly increased shoot phosphorus concentrations when inoculated with two typical fungal associates. The fungal associates also produced significant increases of dry matter production in *C. firmii* compared with uninoculated controls but no growth stimulation was obtained in *C. sempervirens*.

The disturbance of ecosystems may cause a reduction or loss of VA mycorrhizal fungi (Allen et al. 1987; Powell 1980). Allen et al. (1987) surveyed mycorrhizal fungi in several successional areas of the Beartooth Mountains in Montana. Roots were examined for percentage of mycorrhizal

infection and spores were counted in rhizosphere soils from undisturbed, 25 year old seral, and 3 and 7 year old revegetated areas in 1983 and 1984. Unfortunately, their results did not reveal a distinct pattern of change. Spore counts and percent infection of *Deschampsia caespitosa*, *Agropyron trachycaulum*, and *Poa alpina* were higher in undisturbed than seral and revegetated areas in 1983, but in 1984 the spore numbers and infection were similar because values dropped in undisturbed areas and increased in the other areas. However, only a single mycorrhizal fungal species was obtained from the revegetated areas, in contrast to more than 11 species from older areas.

Williams et al. (1984) assayed alpine meadow soils for the nitrogen fixing bacteria (*Rhizobium trifolii*) and VA mycorrhizal fungi. Soils were primarily cold, acid, and well drained. They were sampled at elevations above 3170 m A.S.L. at the Snowy Range Road Project in southeastern Wyoming. Five pots of each soil were planted to *Phleum alpinum* (alpine timothy) and five to *Trifolium pratense* (red clover). All the soils tested were found to contain VA mycorrhizal fungi (Table 37). This was also confirmed by field examination. Results for bioassay of symbiotic microbial associations with *T. pratense* indicated significant ($p<0.05$) differences in number of plant nodules produced from sampling site to sampling site. Total dry weight and total biomass were correlated to number of nodules produced.

Root systems of shrubs collected from sites along the Snowy Range Road were examined in the laboratory for the presence of mycorrhizal fungi. The root systems of all plants examined were found to be infected with mycorrhizal fungi. VA fungi were associated with *Potentilla* and *Ribes* while ectomycorrhizal fungi were associated with willow (Table 38).

A recent study was undertaken to isolate and identify the mycorrhizae within alpine plant communities dominated by ericaceous plants at several locations in the Rocky Mountains of Alberta (Dr. R.S. Currah, Department of Botany, University of Alberta, Edmonton; letter dated March 29, 1990). Fungal root endophytes were isolated from 58 plants belonging to seven species of ericaceous and 14 species of non-ericaceous plants. In a small trial, mycorrhizal isolates were found to have a marked stimulation on the growth of *Menziesia* seedlings *in vitro*.

Table 37. Plant biomass, VAM infection and nodulation of test plants grown on potted soil from the high altitude portion of the Snowy Range Road project.

	Alpine timothy (Phleum alpinum)				Red Clover (Trifolium pratense)				Number of Nodules per Plant
	Plant Biomass (mg/plant)			% VAM Infection	Plant Biomass (mg/plant)			% VAM Infection	
	Tops	Roots	Total		Tops	Roots	Total		
Typic Cryumbrepts, 7 to 12% slope (sampling sites 0,4,5,8 and 13)	31[a] ±12[b]	93 ±46	124 ±54	20.4 ±7.4	73 ±23	156 ±44	240 ±35	42.6 ±16.6	33.8 ±20.2
Typic Cryumbrepts, 12 to 25% slope (sampling sites 2,3,7,11,12, and 14)	31 ±28	121 ±78	152 ±101	15.0 ±13.2	53 ±27	1.27 ±.85	180 ±98	44.7 ±18.3	34.7 ±31.9
Lithic Cryumbrepts (sampling sites 6 and 15)	17 ±8	123 ±59	140 ±67	10.5 ±3.5	67 ±30	172 ±120	239 ±150	32.0 ±8.5	80.6 ±15.0
Cumulic Cryaquolls (sampling sites 1, 9 and 10)	21 ±3	110 ±18	131 ±18	16.7 ±16.1	34 ±4	142 ±52	176 ±52	41.0 ±23.0	60.9 ±15.6

[a] Mean of the bioassays made at the sampling sites located on a particular soil subgroup.
[b] Standard deviation of mean.
Source: Williams et al. (1984)

Table 38. Mycorrhizal activity in soils along the Snowy Range Road

Plant	Type of mycorrhizae	Percent of examined root segments infected	Mycorrhizal fungi present
Salix spp.	ecto	77	*Cenococcum* spp.
Ribes spp.	VA	41	*Acaulospora laevis*
Potentilla fruticosa	VA	35	*Acaulospora laevis* *Acaulospora scrobiculata*
Geum rossii	VA	77	*Glomus clarum* *Glomus fasciculatum*
Festuca spp.	VA	64	*Glomus microcarpum* *Glomus tenue*

Source: Williams et al. (1984)

5.7.2.2 Nitrogen fixation. Low fertility in disturbed high-altitude areas means that plants capable of nitrogen fixation may be particularly useful for reclamation. Nitrogen-fixing plants may possibly increase soil nitrogen levels which could reduce the need for applications of N fertilizer. Alexander and Schell (1973) found significant nitrogen-fixing activity with a variety of higher plants including species of *Dryas* and *Oxytropis* on alpine sites in the Alaska Range. Wojciechowski and Heimbrook (1984) reported nitrogen fixation by *Dryas* and *Trifolium* at Nivot Ridge in the Colorado Rocky Mountains.

Granhall and Lid-Torsvik (1975) found that acetylene reduction activity for *Astragalus alpinus* on an arctic tundra site in Norway occurred at 0 °C, with maximum rates occurring at temperatures between 12 to 15 °C.

In cold tundra, bacterial N_2-fixation is believed to be more critical to plant productivity than in any other terrestrial system (Acharya et al. 1989). Alpine conditions characterized by low soil temperatures and restricted organic decomposition make biological N_2-fixation significant for the survival of plants in these environments (Alexander 1974; Alexander et al.

1978; Wojciechowcki and Heimbrook 1984).Acharya et al. (1989) isolated N_2-fixing bacteria from *Poa alpina* and *Trisetum spicatum* tussock rhizospheres collected from Lookout Mountain (2600 m A.S.L.), Alberta. The genera *Xanthobacter*, *Rhizobium*, and *Bacillus* were identified from isolates grown on nitrogen free agar-medium (NFAM). Seedlings of *P. alpina* grown in NFAM exhibited N-deficiency within 2 weeks of germination, whereas seedlings inoculated with *Azospirillum* or *Azotobacter* species rarely exhibited N-deficiency symptoms. The authors concluded that inoculation of alpine grass selections with appropriate N_2-fixing bacteria may be beneficial for their establishment and survival.

Haselwandter et al. (1983) used acetylene reduction assays to assess nitrogenase activity in sealed pots containing alpine soil and plants *in situ* above 3000 m A.S.L., and in bacterial isolates of soil and rhizosphere in the laboratory. They found that nitrogenase activity could not be detected in bacterial isolates or in soil alone. The absence of free living cyanobacteria from the soil was also confirmed by direct microscopic observation. In pots containing plants, traces of ethylene production were detected for two species: *Poa laxa* and *Cerastium uniflorum*, while no nitrogenase activity could be detected for the other species tested. They suggested that nitrogenase activity detected may be attributed to rhizosphere bacteria. The measured rates of microbial N_2-fixing activity were considered insufficient for vascular plant growth. The authors noted that this is in marked contrast to arctic areas where significant levels of nitrogenase associated with cyanobacteria and lichens have been reported.

However, levels of nitrogen in the alpine soils were found to be comparable to soils of lower altitudes and plant tissue concentrations of nitrogen were also comparable to related herbs or grasses at lower altitudes. Soil and plant tissue phosphorus levels were also comparable to lower altitude levels.

Significant quantities of ammonium and nitrate were measured in soil water and in snowmelt water. Levels of extractable phosphorus in the soil were higher than those considered necessary to support good plant growth. According to their estimates of plant growth, the annual input from snowmelt water was sufficient to satisfy the nitrogen and phosphorus requirements of the plants.

Johnson and Rumbaugh (1986) obtained field estimates of N_2-fixation rates from *Astragalus alpinus*, *Trifolium parryi*, *Trifolium nanum*, *Lupinus caudatus*, and *Lupinus argenteus* growing at high altitudes in Utah and Montana. Although *Astragalus alpinus* and *Trifolium nanum* had the highest specific nodule activities for acetylene reduction, *Lupinus caudatus* showed the greatest acetylene reduction rates on a whole plant basis (nearly 15 times that of any of the other legume species).

Acetylene reduction rates were also measured on disturbed and undisturbed sites at Lulu Pass (2926 m A.S.L.) and Beartooth Pass (3185 m A.S.L.) Montana. At the Lulu Pass site, disturbed soils had pH values of 4.5 to 5.0 with excessive levels of phosphorus, potassium, magnesium, iron, and copper. At the Beartooth Pass site, disturbed soils had pH values of 5.5 to 7.0 with very high concentrations of magnesium and especially calcium.

On a whole plant basis, acetylene reduction rates were significantly higher for plants from the disturbed area than in plants from the undisturbed area at Lulu Pass, but not at the Beartooth Pass site. Plants from the disturbed areas at both Lulu Pass and Beartooth Pass had significantly more nodules than those from the undisturbed sites (Table 39). Plants from the undisturbed area at Beartooth Pass had some of the largest nodules of plants from any of the high altitude sites. The large nodules suggest that they may function over more than one growing season. Perennial nodules may be of adaptive significance in alpine sites as they would allow nitrogen fixation to continue even when conditions are unfavourable for growth of new roots and nodules.

Johnson and Rumbaugh (1981) measured nitrogen fixation activity of *Trifolium parryi* and *Lupinus argenteus* in the field on plants growing at 3207 m A.S.L. in the Beartooth Mountains in Montana. Acetylene reduction rates were measured on excised root fragments with attached nodules (Table 40) and soil cores (Table 41). These results demonstrate that native legume species can fix significant amounts of nitrogen in an alpine environment.

Table 39. Location and site means with associated least significant difference (LSD) values for various characteristics of *Lupinus argenteus* plants sampled for acetylene reduction activity on disturbed and undisturbed high altitude sites[a].

Characteristic	Disturbed Area			Undisturbed Area			LSD (0.05)	
	Lulu Pass	Beartooth Pass	Mean	Lulu Pass	Beartooth Pass	Mean	Loc.	Mean
Shoot dry wt. (g)	7.9	19.3	13.6	4.1	15.7	9.9	7.4	5.2
Root dry wt. (g)	8.5	8.7	8.6	3.6	5.7	4.6	3.0	2.2
Numbers of nodules	79	118	99	33	34	33	58	41
Mean dry wt. of nodule (mg)	26	25	26	18	47	32	26	18
Soil Water content (%)	12.5	5.7	9.1	14.2	8.9	11.6	1.5	1.1
Leaf Water pot. (MPa)	-0.9	-0.6	-0.8	-1.2	-0.8	-1.0	-0.2	-0.2

[a] Values for each location (Lulu Pass and Beartooth Pass) represent means of 12 observations with disturbed and undisturbed means representing 24 observations.
Source: Kenny and Cuany (1990)

Table 40. Acetylene reduction activities of *Trifolium parryi* and *Lupinus argenteus* obtained using excised root segments with attached nodules on August 15, 1979, at Gardner Lake in the Beartooth Mountains in Montana at 3207 m A.S.L.

Species	No. of Samples	Acetylene Reduction (μ moles ethylene per hour) per g nodule fresh weight	per g nodule dry weight
Trifolium parryi	11	38.2	71.0
Lupinus argenteus	12	16.6	31.0
Standard Deviation		3.6	6.9
Significance		0.01[a]	0.01[a]

[a] Significant at 0.01 level of probability.
Source: Johnson and Rumbaugh (1981)

Table 41. Acetylene reduction activities of *Trifolium parryi* and *Lupinus argenteus* obtained using soil cores at Gardner Lake in the Beartooth Mountains in Montana at 3207 m A.S.L. on August 15, 1979.

Species	No. of Samples	Acetylene Reduction (μ moles ethylene per hour) per g nodule fresh weight	per g nodule dry weight	per cc soil
Trifolium parryi	6	57.6	109.7	0.0051
Lupinus argenteus	6	21.3	57.3	0.0071
Standard Deviation		12.5	22.4	0.0008
Significance		0.1[a]	NS	NS

[a] Significant at 0.10 level of probability
Source: Johnson and Rumbaugh (1981)

Acetylene reduction was determined for *Lupinus argenteus* on adjacent disturbed and undisturbed sites at 2975 m A.S.L. near Cooke City, Montana. The disturbed site had coarse-textured gravel materials where organic material had been removed during road construction. Vegetation cover consisted of isolated plants of *Lupinus argenteus* and *Deschampsia caespitosa*. The undisturbed site had abundant *Lupinus argenteus* in a dense forb vegetation cover. Acetylene reduction activities measured on excised root segments were significantly higher on the disturbed site than on the undisturbed site (Table 42).

Kenny and Cuany (1990) determined whether pioneering lupines (*Lupinus argenteus*, *L. caudatus*, and *L. alpestris)* increased the nitrogen content of soils. Two soil samples were collected from a 10 cm depth, 10 cm from lupine tap roots and an additional two samples were obtained at a 10 cm depth, 3 m from lupine plants. As the samples were taken, root fragments, nodules, and dead plant fragments were removed. Paired samples were taken from 33 disturbed sites which had lupines as the dominant vegetation. The

Table 42. Acetylene reduction activities of *Lupinus argenteus* obtained using excised root segments with attached nodules at Lulu Pass in the Beartooth Mountains in Montana at 2975 m A.S.L. on August 16, 1979.

Site	No. of Samples	Acetylene reduction (μ moles ethylene per hour) per g nodule fresh weight	per g nodule dry weight
Disturbed	12	9.1	26.1
Undisturbed	11	4.7	12.6
Standard Deviation		2.1	5.5
Significance		0.1[a]	0.01[b]

[a] Significant at 0.10 level of probability.
[b] Significant at 0.01 level of probability.
Source: Johnson and Rumbaugh (1981)

sites were all located in the Rocky Mountains of Colorado and ranged in elevation from 2130 m A.S.L. to 3350 m A.S.L. They included road construction disturbances, abandoned mine tailings, open meadows created by fires, ski slopes, construction or logging operations, and a sand dune.

Soil samples collected 10 cm from lupine tap roots averaged 13.8 mg kg^{-1} more exchangeable ammonium and 2.7 mg kg^{-1} more nitrate than soil samples collected 3 m from lupin plants.

Acetylene reduction (to ethylene) measurements were also made on excised root fragments at 12 of the disturbed sites to estimate nitrogen fixation. Acetylene reduction rates averaged 10 μmol ethylene g^{-1} nodule dry weight h^{-1} for *L. argenteus* and 17.3 μmol ethylene g^{-1} nodule dry weight h^{-1} for *L. alpestris* (Table 43).

Table 43. Field measured acetylene reduction by native lupines growing on disturbed mountain sites in Colorado.

Species and site	Elevation m A.S.L.	Sampling conditions: Site description	Time	Temperature: Air (°C)	Temperature: Soil (°C)	Sky	Ethylene production[a] (μ mole g^{-1} nodule dry wt.$^{-1}$)
L. argenteus							
North Sand Hills	2926	Sand dune	1315	26	17	Clear	29.6±7.6
Dumont Lake	2896	Roadside with grasses	0915	18	11	Clear	16.9±9.4
Blue River	3048	Roadside with grasses	1230	18	14	Cloudy	7.4±0.5
Tennessee Pass	3048	Clearing in lodgepole pine re-growth forest	1800	22	14	Cloudy	6.7±2.4
Hoosiet Pass	3109	Roadside with grasses	1200	17	10	Cloudy	4.3±2.2
Climax	3353	Molybdenum tailings	0945	22	11	Clear	1.2±0.4
L. alpestris							
Hideaway Park	2682	Roadside with grasses	1530	26	17	Clear	18.0±0.4
Hot Sulphur Springs	2347	Roadside with grasses	1730	21	15	Clear	16.6±5.5

[a] Mean ± Standard Deviation.
Source: Kenny and Cuany (1990)

These results indicate that these lupine species can fix nitrogen on disturbed alpine sites and increase levels of soil inorganic nitrogen. The authors concluded that these pioneer species are potentially useful revegetation plants for disturbed sites.

5.7.3 Fertilization

Brown and Johnston (1980a) used a bioassay to study the effectiveness of various amendments to mine spoils on the growth of two grass species. The spoil came from the McLaren Mine on the Beartooth Plateau in southern Montana. A total of seven amendments were prepared. These included:

1. Control: no amendments added to the spoil material.
2. Fertilizer: a granular 18-24-5 N-P-K ratio fertilizer was incorporated into the spoil at a rate to provide about 111 kg N per ha.
3. Fertilizer-lime: fertilizer was added as in 2 above, plus hydrated lime was incorporated at an equivalent rate of 2240 kg per ha, to raise soil pH.

4. Fertilizer-lime-straw: fertilizer and lime amendments were added as described above. Straw was added at an equivalent rate of 5% by volume.
5. Fertilizer-straw: fertilizer and straw were added as described above.
6. Fertilizer-lime-manure: fertilizer and lime amendments were added as described above. Manure was added at an equivalent rate of 5% by volume.
7. Fertilizer-manure: fertilizer and steer manure were added as described above.

Deschampsia caespitosa (tufted hairgrass) and *Alopecurus pratensis* (Garrison meadow foxtail) were seeded into containers filled with each of the seven types of amended spoil.

The results indicated that amendments did not have a significant effect on seed germination or plant emergence. However, where fertilizer and manure were incorporated into the spoil material plant growth was substantially improved. Straw incorporated into the spoil resulted in greater levels of growth than the control or fertilizer treatments but was not as effective as manure. The addition of lime tended to slightly depress plant growth on these slightly acid (pH 6.1) spoils presumably because the plant species used were adapted to moderately acid conditions.

Brown and Johnston (1976) found topsoil and fertilizer amendments to an acid (pH 3.8) mine spoil improved plant survival and growth after one growing season. The study site was located at the McLaren Mine at 2950 m A.S.L., near Cooke City, southwest Montana.

Plant densities were higher on fertilized plots, except for the introduced species on the topsoiled plots which showed no appreciable difference between the fertilized and unfertilized treatments (Table 44).

Plants growing on fertilized plots were taller and had deeper roots than the same species on the unfertilized plots. However, total plant cover on all plots was very low with the highest cover estimated to be only about 2%, reflecting the small size of the plants.

Table 44. First year results of plant density on the McLaren Mine revegetation plots (average number of plants per m^2).

Species	Topsoil		Spoil	
	Fertilizer	No Fertilizer	Fertilizer	No Fertilizer
Introduced	360	401	84	26
Native	1306	1044	895	96

Source: Brown and Johnston (1976)

Brown et al. (1976) considered fertilizer applications essential to the successful and rapid establishment of plant cover on alpine disturbances. They found that:

1. Application rate should be based on soil testing.
2. Fertilizer should be applied just prior to seeding.
3. Fertilizer should be mixed to 6 to 7 cm depth.
4. Application rates of 111 kg/ha-N have been successful on the Beartooth Plateau.
5. Follow-up fertilizer in small amounts may be required to maintain plant vigour.

A single application rate of 111 kg/ha N maintained a level of productivity about 100 times greater than that of unfertilized plots, over a 3 year period. Unfertilized plots showed little or no plant development after 3 years, even on those plots receiving heavy applications of organic matter. Fertilizer applications were essential for plant establishment while organic matter and/or topsoil amendments enhanced the rate of stand establishment.

Brown and Johnston (1976) recommended that fertilizer and other required amendments should be incorporated into the upper 15 to 30 cm of soil or spoil to be available within the rooting zone of germinating seedlings and developing young plants.

Nitrogen deficiency is the most persistent soil fertility problem commonly encountered in the revegetation of coarse-textured subsoils and glacial tills in the subalpine (Berg and Barrau 1978). Takyi and Islam

(1985a) found that discontinuation of maintenance fertilization for only 2 years lead to a drastic decline in plant cover and production on infertile, calcareous mine spoil in the subalpine in Alberta. The grass/legume mixture consisted of creeping red fescue, Canada bluegrass, timothy, and white clover, although the clover failed to persist. Even after 6 years of maintenance fertilization, little nutrient reserves had built up in the coarse-textured spoil. The reduction in plant productivity was attributed to nitrogen deficiency. Two years after fertilization was reintroduced, productivity increased but was still below values obtained prior to the initial fertilization being discontinued. It appears that once productivity was interrupted by withholding fertilizers, it would take several years of maintenance fertilization to restore plant productivity.

Ziemkiewicz (1982) also found that withdrawal of maintenance fertilization caused a severe decline in shoot and root production on reclaimed coal mine spoil in the subalpine (2100 m A.S.L.) in southeastern British Columbia. Paired plots were established on reclaimed coal mine spoil and undisturbed native grasslands. Plant shoots, roots, detritus, and soils were monitored for N, P, K, and organic matter over a 14 month period. Midway through the study one of the paired plots on each site was fertilized and the other left unfertilized. In the subalpine reclaimed area detrital N and P increased almost continuously throughout the year. There was only a slight loss in detrital N and P between June and August, a period when plant growth was reduced and plants were already losing biomass. N and P were immobilized to the greatest extent in the detritus while K was readily leached from the detritus. The accumulation of N and P in the detritus at the subalpine site was attributed to inhibition of detrital decomposition as a result of low decomposer populations, mid-summer drying, and low temperatures. Ziemkiewicz suggested that at subalpine and alpine locations reclaimed areas may require long periods of maintenance fertilization.

Other reclamation studies in the arctic and alpine have reported good initial growth but poor persistence (Brown et al. 1978b). The decline in vigour is often associated with an accumulation of detritus on the soil surface (Younkin 1976).

In cold environments, the decomposition of dead plant material is slow because of the low temperatures, high C:N, P ratios, and low decomposer populations. Native alpine plants seem to have adapted to these slow rates of nutrient cycling. Firstly, they have very slow growth rates. Secondly they tend to exhibit high proportions of root biomass to shoot biomass. Nutrients and carbohydrates are stored in the large root system. This 'in plant cycling' provides nutrients to the plant during the critical early growing season and releases the plant from total dependence on detritus supplied nutrients (Chapin 1980; Ziemkiewicz 1982).

Urbanska (1986) noted that alpine plants do not require extensive fertilizer application because their life strategy is based on growth efficiency rather than high growth rates. Heavy doses of fertilizer where considered superfluous when native alpine plants are used in reclamation.

Berg and Barrau (1978) reported on several nitrogen fertilization studies in the subalpine in Colorado. The first study was located on a 11° (20%) south-facing slope at 3350 m A.S.L. The glacial till material had a sandy loam texture with a pH of 8.1. It was extremely low in extractable phosphorus and low in potassium. The site was fertilized with triple superphosphate (168 kg P_2O_5/ha) and sown with *Bromus inermis*, *Phleum pratense*, *Agrostis alba*, *Festuca rubra*, *Festuca ovina* var. *duriuscula*, *Dactylis glomerata*, and *Trifolium repens*. Nitrogen as NH_4NO_3 was applied progressively for the next 4 years (Table 45).

Table 45. Rates of nitrogen applied in a given year and resultant ground cover.

Treatment (Applied each June)		Total N Applied (kg/ha)	Ground Cover (%) (August 1977)
No N		0	5
67 kg N/ha	1974	67	10
67 kg N/ha	1974 & 1975	134	25
67 kg N/ha	1974, 1975 & 1976	210	33
67 kg N/ha	1974, 1975, 1976 & 1977	268	40

Source: Berg and Barrau (1978)

After 4 years the residual effects of N applied in 1974 was small. The residual affect of N applied in 1974 and 1975 was considerable. The addition of N in 1976 was not as effective in producing plant cover as that applied in 1975. A similar trial at a second site with an acid (pH 6.5), sand loam till with a high coarse fragment content (70% rock and gravel) yielded very similar results. Berg and Barrau concluded that the most effective method of N fertilization was to apply N in both the first and early in the second or third growing seasons and then wait several years until the stand becomes N deficient before applying another N application. This might be at 3 or 4 year intervals.

Mitchell (1987) recommended a schedule of applying fertilizer in the first and third growing seasons on coal mine overburden materials located above treeline in the interior of south-central Alaska. Another application in the fifth and sixth growing year was also recommended to help establish the threshold of fertility necessary for a self-sustaining community providing adequate cover. A fertilizer containing nitrogen, phosphate, and potash in percentages of 20, 20, and 15, respectively applied at 400 to 450 kg/ha was considered adequate.

Periodic application of N fertilizers may limit natural succession, possibly of species with lower N requirements. Chapin (1980) noted that as nutrient availability increases, rapidly growing species from fertile sites respond with greatly increased growth rates, whereas species from infertile sites show less growth response but increased tissue concentrations. In addition, the major criterion for recognizing nutrient limitation in crops (i.e., a large growth response to addition of a limited nutrient) is invalid and would give contrary results if different wild species, each growing in its normal habitat, were compared.

The effects of mulch and fertility treatments applied at or near the time of seeding were determined 7 years after seeding several disturbed sites in the Colorado alpine. The two sites were a silty clay loam subsoil 130 m above treeline and mine rock waste 330 m above treeline. These have been described previously (see Guillaume et al. (1986) in Section 5.6.2).

The fertility treatments applied to individual 3 m by 9 m plots included chemical fertilizers and sewage sludge. Two rates of fertilizer were used:

1. Diammonium phosphate (18-46-0) applied at the rate of 336 kg/ha prior to seeding in October 1978.
2. Same as 1. plus 112 kg N/ha as NH_4NO_3 applied in June 1980.

Sewage sludge was applied at rates of 11, 22, 44, and 88 Mg/ha. This was equivalent to 62, 124, 248, and 496 kg N/ha. The dry primary sludge contained about 13% organic matter (Table 46). Woodchips at a rate of 44 Mg/ha were added to all sludge treatments. The purpose of woodchips was to immobilize and conserve some of the nitrogen in the sludge applied to the coarse rock waste.

Sites were assessed for vegetation cover and species frequency during the second (1980) and seventh (1985) growing seasons after seeding. No significant differences were observed among treatments after the second growing season. After the seventh growing season, vegetation ground cover was 1.5 to 2.5 times greater on the high rate sewage treatments than on the fertilizer treatments. No consistent difference in vegetation cover was evident between the two fertilizer treatments. The lower rate of sewage sludge produced vegetation cover similar to that produced by the fertilizer treatments. The frequency of native species was similar on low and high fertility treatments. Increases in vegetation cover produced in response to the fertility treatments were not affected by the type of mulch used. However, the increase in vegetation cover of native species with increased rates of sewage sludge indicates that fertility, probably plant-available nitrogen, is limiting plant growth. Even at the highest sewage sludge rate, dry matter production is about half that produced on an adjacent *Deschampsia* meadow.

Brown et al. (1984) investigated the influence of repeated fertilizer application on species composition, plant cover, plant density, and above- and below-ground productivity. The study site was located on the McLaren mine in the Beartooth Mountains in southwestern Montana. It was located on a southwest aspect with a 8° (15%) slope. Lime and manure were applied at a rate of 2000 kg/ha. Fertilizer (16-40-5) was applied at a rate of 112 kg N/ha, 280 kg P/ha, and 35 kg K/ha at time of seeding. The area was seeded with a mixture of native grasses and then straw mulch was added at a rate of 2500 kg/ha. The site was refertilized in 1977, 1978 and 1979. In

Table 46. Chemical characteristics of subsoil, rock waste, cover soil, and sewage sludge used in fertility and mulch studies.

Material	pH	EC[a] dS/m	Organic Matter (%)	Extractable Nutrients (ppm) NO_3-N	P	K	Zn	Fe
Subsoil	5.0	0.1	1.3	1	11	35	1	83
Rock Waste	5.1	0.6	0.4	1	20	113	4	124
Cover Soil	6.3	0.6	4.7	5	6	73	69	170
Sewage Sludge	6.7	11.0	13	62	142	825	204	145

[a] EC determined in saturated extract; P, K, Zn, Fe in NH_4HCO_3-DTPA extract
Source: Berg et al. (1986)

Table 47. Summary of fertilization treatments on the McLaren Mine Demonstration Area by year. "X" refers to fertilizer applications.

Year	Treatments 1	2	3	4
1976[a]	X	X	X	X
1977	X	X	X	X
1978	X	X	X	X
1979	X	X	X	X
1980		X	X	X
1981			X	X
1982				X

[a] Year of installation
Source: Brown et al. (1984)

1980, the site was split into four subplots, and fertilizer was applied according to the schedule given in Table 47.

Plant density, cover, and production were found to show no increases with repeated application of fertilizer over time. There was no

consistent trend from treatments one through four (Table 47). The authors noted that differences in site conditions among the four treatment areas were sufficiently large to mask any effect of the fertilizer treatments. When the data from any one treatment were examined, a large variation in response was evident. This suggested that climatic variables (precipitation, snowpack accumulation, and possibly growing season temperatures), which vary significantly from year to year, could have influenced growth responses and masked the treatment effects. Adjacent alpine plant communities were observed to have large variations in plant growth from year to year. After seven growing seasons there was little change in the species composition from that of earlier years. It would be expected that later successional species would begin to invade and compete with the early seral species originally seeded. This may have been influenced by the repeated fertilizer applications on the plots.

The response of native and agronomic species to three fertilizer regimes was tested by Walker (1982) at the Lake Louise ski area. The trials were located on a 25° east-facing slope at treeline (2300 m A.S.L.). Soils were a well-drained sandy clay that is slightly alkaline, and low in nitrogen and phosphorus. The fertilizer treatments consisted of ammonium nitrate (26-13-0) applied at 100 kg-N/ha, 25 kg-N/ha, and 0 kg-N/ha at the time of growth initiation. There were three replications of each treatment.

The rate of N fertilizer application was found to have no significant effect on seedling establishment. However, after three growing seasons ground cover for all live species at the high N rate of fertilizer was 37%. This was significantly ($P<0.01$) greater than that for the low N (<4%) and the no N (<1%).

In the Peace River (Northeast) Coal Block region of British Columbia, Errington (1979) conducted a fertilizer trial to examine the response of a species mix to eight fertilizer treatments (Table 48).

Five sites were chosen at elevations ranging from 1675 m A.S.L. to 1745 m A.S.L. Soil textures were silty loams and silty clay loams with varying coarse fragment content. Soil nutrient analysis was completed, but results not provided. All sites were seeded with the same species mix at 56 kg/ha. Three of the sites were seeded in the fall and two in the spring. Results indicated that the growth response of the species mix at the three

Table 48. Fertilizer trial rates used in the northeast Coal Block region.

	Rate of Nutrient Applied (kg/ha)		
Treatment	Nitrogen	Phosphorus	Potassium
Control	0	0	0
N only	46	0	0
P only	0	18	0
K only	0	0	60
N, P	16	20	0
N, K	46	0	60
P, K	0	18	60
N, P, K	16	20	60

Source: Errington (1979)

fall seeded sites was similar to the two spring seeded sites. At all sites, growth response was greatest on plots receiving complete fertilizer(N, P, K). However, a fertilizer containing only nitrogen and phosphorus appeared adequate at most sites tested.

The effect of fertilizer treatment on native and agronomic grass species was examined by Sadasivaiah and Weijer (1982) at the Ptarmigan site, 40 miles west of Banff. The trial site (2290 m A.S.L.) was located on an east-facing slope of 10 to 30 degrees. The coarse-textured soils were developed on glacial till.

Nine replications of nineteen native and four agronomic species were established. Two rates of inorganic fertilizer (26-13-0) at 100 kg/ha and 25 kg/ha were applied to six of the replications, while three were left unfertilized. Applications of fertilizer at the time of seeding had no effect on seedling establishment of either native or agronomic species. Although fertilizers were found to increase native species biomass, they did not influence tillering ability.

Operational fertilizer applications were described by Brown (1974) for the Climax Mine in Colorado. Soils formed in glacial till contained isolated pockets of peat and sand deposits. Soil infertility was particularly evident where disturbance had removed the A horizon.

An initial application of 90 kg (12-12-12) resulted in low soil phosphorus levels, hence increased phosphorus rates were tried. Results of the increased application were not reported.

Comparisons of the effectiveness of urea-formaldehyde and ammonium nitrate fertilizers indicated that inadequate amounts of nitrogen were released from urea-formaldehyde to meet plant requirements. Brown (1974) attributed this to low or inactive soil bacteria populations as a result of the low soil temperatures at these high elevations.

Maintenance fertilizer programs were found to be imperative to maintain vegetation cover on exposed subsoils. Fertilizer was applied in June, July, late September, or October. The maintenance program at the Climax Mine was directed to top-dressing fertilizer not less than every other year until the stand has shown the ability to maintain adequate ground cover to control erosion without further nitrogen fertilization.

6. SUMMARY AND RECOMMENDATIONS

This section of the report provides a summary of the main research findings relevant to reclamation of alpine lands in Alberta and a list of research needs noted in the literature. These findings are presented in the order which is likely to be followed by a developer namely: reclamation planning, site preparation, surface preparation, and revegetation. Because of the variability of site conditions, and the lack of an adequate data base, site specific recommendations cannot be provided. The approach taken is to provide the developer with a framework in which to develop a site specific reclamation plan. It is important to note that this section is presented as if the developer has the appropriate permits and approvals to conduct a disturbance on an alpine site. While section 2. provides a brief overview of some of the relevant acts, regulations and policies that may apply to development of the alpine, the reader is cautioned that this is by no means a complete coverage of this subject; it is up to the developer to contact the appropriate agencies to find out what the requirements will be. A considerable amount of data will be required to get the required approvals.

Research to date in North America has primarily concentrated on identification and selection of plant materials which can withstand the harsh conditions of the alpine. Research on methods to enhance the establishment of plant cover including such factors as surface preparation, use of mulches, and fertilization has been sparse and has often yielded contradictory results.

Economics will obviously play a part in any decision to undertake development in the alpine region. This review has not covered the costs of reclamation in the alpine, however many of the methods described are going to be expensive. In particular, the use of special equipment for soil handling and revegetation, the use of mulches, and the use of native species may result in additional costs. The reader is encouraged to delve further into the literature cited, and other specialized literature to determine potential costs for reclamation of a particular site.

6.1 RECLAMATION PLANNING

Reclamation in the alpine is a difficult process. The climate is harsh, the soils are often coarse-textured and nutrient poor, and temperatures

can fluctuate widely both daily and seasonally. Alpine environments, therefore, represent the ecological limits of many plant species.

On a given alpine site, the distribution of plants and soils is strongly influenced by topography through its influence on solar radiation, soil moisture, soil and air temperatures, and both the abrasive and protecting aspects of snow. This diversity of sites in the alpine environment can complicate reclamation planning, requiring that reclamation prescriptions be site specific and often for small areas, rather than general prescriptions that apply to large areas.

6.1.1 Management Units

Burns (1980) recognized the importance of site conditions to plant growth potential in the alpine and developed a system of management units which can be utilized for reclamation planning, and to identify sensitivity of sites to disturbance. These management units can be delineated on the basis of snow accumulation, drainage, soils, and vegetation cover as indicated in Table 49. A knowledge of the location of these units should be acquired prior to development and may take several years to accumulate. Photographs of the site during the winter and spring snowmelt may be a useful means of identifying the various management units. Identification of these units is critical to the success of reclamation as site preparation and revegetation specifications are related directly to these units.

6.1.2 Land-use Options and Reclamation Objectives

Wildlife range, watershed protection, and recreation use are the main land-uses at present in the alpine in Alberta. The potential for changing post-disturbance land-uses is limited in the alpine because of the extremely harsh climatic conditions and the limited choice of plant species suitable for revegetation. Reclamation effects to date have, therefore, emphasized techniques to re-establish vegetation cover.

The primary short-term reclamation objective is to provide a stabilizing plant cover to prevent erosion. Over the long-term, the reclamation objective it is to establish a self-sustaining plant community that permits recolonization by native plants of the local area. This will ulti-

Table 49. Sensitivity to disturbance and ease of revegetation in relation to management unit.

Management Unit	Slope	Drainage	Soil Features	Dominant Vegetation	Sensitivity to Disturbance	Ease of Revegetation
Extremely windblown (EWB)	Ridge tops and upper slopes	Rapidly drained	Exposed rock, shallow soil, wind erosion	None to stonefield lichen	Low	Very low to nil
Windblown (WB)	Upper slopes	Rapidly to well drained	Shallow soil, soil creep and wind erosion	Dryas and stonefieid lichen	Low	Low
Minimal snow cover (MSC)	Mid to upper slopes south- and west-facing	Well drained	Brunisol and Regosol	Festuca, Kobresia and Dryas	Low to Medium	Low to Medium
Early melting snowbank (EMS)[a]	Mid slopes to level areas	Well to moderately well drained	Brunisol and Podzol, soil creep	Phyllodoce and Cassiope	Medium	Medium
Late melting snowbank (LMS)[a]	Mid slopes and valley bottoms	Moderately well to imperfectly drained	Brunisol and Regosol, soil creep	Cassiope, Dryas and Salix	High	Medium
Perennial snowbank (PS)	Lee slopes and valley bottoms	Poorly drained	Regosol, soil creep	None to Cassiope and Salix	High	Not Applicable
Wet Meadow (WM)	Lower slopes and valleys	Imperfectly to poorly drained	Brunisol, Regosol and Mesisol	Salix and Carex	High	Medium to High

[a] These terms are relative. The specific time of snow melt will depend on site location.

mately result in vegetation cover similar to that of nearby undisturbed native plant communities.

6.1.3 Type of Disturbance

The techniques of site preparation (contouring), surface preparation, drainage and erosion control and revegetation are dependant on the type of disturbance. Planning considerations and reclamation strategies for various types of disturbances in the alpine are summarized in Table 50 and briefly described in the following sections.

6.2 SITE PREPARATION

Site preparation involves a number of practices with the objective of modifying site conditions to conform to the post-disturbance land-use and in preparation for revegetation. A knowledge of snow deposition and snowmelt patterns and the locations of recharge and discharge areas is important for planning site preparation.

6.2.1 Contouring

Contouring should be designed to facilitate ease of revegetation. Slopes should be reshaped to minimize slope angles and provide uniform slopes. This will prevent ridges that are barren in winter, very dry in summer, and subject to wind erosion. Snow distribution is the most important physical factor controlling plant development in the alpine. Slopes should be contoured to remove depressions. These have excessive snow accumulation and resultant short wet growing seasons. Contours that result in the ponding of surface water should be avoided to help prevent erosion, gullying, and mass slumping. Uniform slopes will have more even snow distribution which promotes uniform infiltration of snowmelt water, a more regulated rate of runoff, and evenly distributed plant emergence and development.

However, where the goal of reclamation is to establish a variety of vegetation communities, the preparation of uniform slopes may not provide appropriate conditions to meet this objective. Furthermore, wind swept slopes may benefit from "pockets" where vegetation can establish in shelter. A developer must balance the need for easier reclamation with the ultimate reclamation goal.

Table 50. Summary of planning considerations and reclamation strategies for various types of disturbance in the alpine.

Type of Disturbance	Planning Considerations	Contouring	Drainage and Erosion Control	Surface Preparation	Revegetation
Hiking Trail Development	Wet meadow, later melting snowbank and exposed sites are sensitive to disturbance; visual impacts; patterns of hiker use before and after construction; special terrain features (attractions); wildlife; turf salvage.	Backslope cutbanks 2:1 or 3:1; round off turf cap to smooth transition.	Where trails cross natural drainages - install cross drainages with slope of 9 to 11°. Low profile swales lined with rock for low flows, open timber lined ditches for heavy flows.	Topdress badly eroded areas with topsoil; loosen soil surface by harrowing or raking to incorporate seed and fertilizer into soil.	Transplanting sod very successful on mesic to wet sites, use roll out paper mulch on dry sites that have been seeded. Match seed mixture to topographic unit.
Ski Field Development	Visual impacts; avalanche risk; sensitive areas; drainage and erosion control; construction timing; special construction techniques e.g., helicopters.	Keep area of slope modification to minimum; disturbed slopes greater than 40° difficult to revegetate.	Construct waterbars on slopes greater than 10°; slope of waterbar 1 to 2° at high end then increasing to 3 to 5° at discharge end.	Loosen soil surface by harrowing or raking to incorporate seed and fertilizer into soil; difficult to revegetate sites may be amended with horse manure (30 tonnes/ha).	Start revegetation immediately after final grading; maximum size to be revegetated at a given time should be about 2.0 ha; for slopes less than 15° mulch after seeding with native hay[a] (2000 to 3000 kg/ha) or hydroseed wood fibre; use jute or roll out paper mulch on slopes greater than 15°.
Road Construction	Impact on snow distribution; soil stability; visual impacts, sensitive areas, soil and turf salvage, drainage and erosion control.	Backslope cutbanks 2:1 or 3:1; round off turf cap to smooth transition.	Construct waterbars on long slopes; slope of waterbar 1 to 2° at high end then increasing to 3 to 5° at discharge end.	Leave surface of cut slopes rough; where possible topdress with topsoil; pack fill slopes; loosen soil surface by harrowing or raking.	Transplanting sod particularly on cut slopes; fill slopes easier to revegetate by seed; match seed mixture to topographic unit; transplanting on difficult sites; mulch after seeding with hay[a] (2 to 3000 kg/ha), hydroseeding wood fibre or roll out paper mulch.
Mining	Impact on snow distribution; soil stability; sensitive areas; visual impacts; soil salvage; drainage and erosion control.	Where possible eliminate ridges which tend to scour in winter and dry out in summer; contour to smooth slopes with even snow distribution. Remove depressions which become pockets of snow accumulation.	Construct waterbars on long slopes; slope of waterbar 1 to 2° at high end then increasing to 3 to 5° at discharge end.	Where possible topdress with topsoil; manure strongly recommended for non-topsoiled sites; snowfences to improve snow accumulation on bare sites; loosen soil surface by harrowing or raking, to incorporate seed and fertilizer into soil.	Match seed mixture to topographic unit; mulch after seeding with hay[a] (2000 to 3000 kg/ha), hydroseeding wood fibre or roll out paper mulch; transplanting on difficult sites.

[a] Hay may not decompose in alpine areas, and may detract from revegetation efforts by smothering developing plants (pers. comm. Gail Harrison, Canadian Parks Service).

6.2.2 Slopes

When cut slopes are constructed the surface should be left uniform but rough to assist binding of topsoil to the subsoil. If the slope surfaces are smooth they should be loosened before topsoil is applied. Fill slopes near the angle of repose should be mechanically packed to make them firm and stable.

It has been found that long and/or steep spoil slopes are subject to severe mass wasting and other forms of erosion, with resultant problems in terms of revegetation and sediment production in local water courses. Where possible, spoil slopes should not exceed 15°; the use of terraces to break up long slopes may help further reduce the risk of erosion, however, the literature was inconclusive on this method. In addition, the revegetation of steep south and west-facing slopes is often difficult because of high surface soil temperatures produced by heavy direct insolation. Reduced slope angles will help mitigate this effect.

6.3 SURFACE PREPARATION

Surface preparation involves measures to provide the best seedbed possible for revegetation.

6.3.1 Soil Replacement

The addition of topsoil to disturbed spoils in both the alpine and the subalpine has been shown to greatly enhance plant establishment and growth, and to reduce the need for maintenance fertilization at subalpine and alpine elevations. Topsoil provides a better seedbed with superior structure and soil nutrient status.

Alpine soils are extremely variable even over short distances. They vary greatly in depth, fertility, and susceptibility to erosion, although they tend to be shallow, poorly developed, and have high coarse fragment contents.

Topography, through its control of snow distribution, is the most important factor controlling soil distribution and development. Depth of the A horizon (topsoil) tends to be greatest on minimal snow cover, early melting snowbank and wet meadow sites. The organic surface horizon is usually a densely rooted turf. It is the organic matter in this horizon that imparts

stability to alpine soils. In addition, available nitrogen and phosphorus levels tend to be highest in this horizon.

At present there is insufficient information to propose detailed guidelines on acceptable limits for soil salvage and replacement. The choice of salvage materials should be based on the need to provide an improved seedbed to that of the disturbed spoil. Soils with properties likely to provide a better seedbed should be salvaged. In practice, the nature of the terrain and the variability in soils will determine the efficiency of salvage and the amounts of soil salvaged.

6.3.1.1 Topsoil quality. One researcher has noted that topsoil should have a minimum plant available moisture capacity of 7%. Organic matter content should be in the range of 1% to 20%. A clay content of 30% to 35% should be the maximum.

There is insufficient information to establish detailed guidelines for assessing topsoil quality. It is important to note that topsoil may need to be stripped together with other horizons thus potentially reducing the quality of the topsoil; care will need to be taken in how much mixing can be tolerated before the topsoil becomes unsuitable for plant growth.

6.3.1.2 Topsoil depth. A depth of 10 to 15 cm of topsoil is considered optimum for most vegetation communities; however, some, such as *Cassiope* spp. may require a deeper horizon. It is not practical to spread topsoil less than 5 cm deep unless the area is relatively level and the underlying material has enough fines to aid plant establishment. Placing topsoil more than 15 cm deep on a fill or cut slope is not recommended because of soil slumping. Smoothly bladed slopes with a thick layer of topsoil may slide when the soil becomes saturated.

In practice the amount of soil available and the efficiency of salvage will dictate the amount used. As south-facing slopes have greater risk of summer drought, limited topsoil supplies should be first placed on those slopes.

6.3.2 Organic Matter Additions

The incorporation of organic matter into the soil can greatly improve plant growth, nutrient holding capability and soil water holding capacity. It can also help reduce high surface temperatures during the growing season. Peat moss, manure and straw have been used successfully at rates of 2000 to 4000 kg/ha. The organic amendments should be worked into the soil to a depth of at least 15 cm.

6.3.3 Cultivation

The soil surface of the site should be loosened by ripping, roto-tilling, harrowing, or raking to improve aeration and moisture penetration. Following seeding, firm packing of the seedbed, preferably with a seed packer, is important to ensure intimate contact between seed and soil and has been found to greatly enhance stand establishment. Soils high in rock and stone content may be left in a worse condition if cultivated since the fine soil fractions may be shifted down in the soil profile.

6.3.4 Surface Mulches

Soils in alpine areas are subject to the formation of needle-ice during the short-growing season particularly in the spring and late summer. Alpine soils are also subject to drought during the growing season. Mulches can reduce moisture loss through evaporation and reduce needle-ice formation, and can thereby enhance seedling establishment. On the other hand, the insulating effect of mulches can decrease the growing season by keeping the soil cooler longer in spring. Mulches can also lessen the loss of fine soil particles due to wind erosion.

However, field trials with mulches have yielded mixed and inconclusive results. Straw mulch tacked down with a water based asphalt has been used with mixed results. A peat moss mulch has been found to either have no significant influence or retarded seedling establishment. A roll out paper mulch has been used successfully, particularly on dry sites. Mulches, especially those composed of straw may not degrade quickly in alpine areas, which may be good if long-term erosion control is the objective, but may also be bad if a "natural look" is desired.

6.4 REVEGETATION

There has been a good deal of research in North America on selection of plant species suitable for use in alpine reclamation. Native species and a short list of agronomic species with potential for use in the alpine in Alberta are given in Tables 51 to 54.

6.4.1 Species Selection

Only plant species known to be adapted to alpine conditions should be used. They should have the following characteristics:

1. Colonizer species;
2. Cold (and drought) tolerant;
3. Tolerant of low nutrient levels so that a self-sustaining cover can be achieved;
4. Low competitive ability (agronomic species) so that natural succession can be encouraged; and,
5. Seed is available.

Several seed mixtures will likely be required to successfully and efficiently revegetate a large disturbance area. These mixtures should be matched to the microsites to which the component plant species are best adapted. It is recommended that mixtures of low growth rate and low nutrient-adapted (native species) and high growth rate and high nutrient-adapted (agronomic species) be used. This will:

1. Provide cover and forage more quickly than mixtures of just native species; and,
2. Provide for establishment of native species more quickly than by natural invasion.

Overly competitive species should be excluded to ensure compatability among species in the mixture. When utilizing native species, collection of seed in the vicinity of the disturbance is most desirable to ensure adaptability to the site. Since seed production in the alpine is often sporadic, several years may be required in order to obtain the necessary volume and the desired species.

Table 51. List of native grass species having potential for reclamation of alpine areas in Alberta.

Species	Common name	Successional Stage	Recommended Site[a]	Establishment Method[b]	Commercially Available	Comments
Agropyron dasystachyum	Northern wheatgrass	Early seral	MSC, EMS	S, T	Yes	Drought tolerant and persistent
A. scribneri	Wheatgrass	Early seral	MSC, EMS	S, T	No	Winter hardy
A. trachycaulum	Slender wheatgrass	Early seral	MSC, EMS	S, T	Yes	Winter hardy, erosion control, browse tolerant
Agrostis scabra	Hair grass	Early seral	MSC, EMS	S	No	Winter hardy, erosion control
Carex spp.	Sedges	Early and late seral	LMS, WM	S, T	No	Tolerates wet soil, erosion control, wildlife habitat
Deschampsia caespitosa	Tufted hair grass	Early seral	MSC, EMS	S, T	Yes	Winter hardy, erosion control
Eriophorum angustifolium	Cotton grass	Early and late seral	LMS, WM	S, T	No	Tolerates wet soil, winter hardy, wildlife habitat
Festuca idahoensis	Bluebunch fescue	Early seral	MSC, EMS	S, T	No	Winter hardy
Festuca saximontana	Fescue	Early seral	MSC, EMS	S, T	No	Winter hardy, palatable, low alpine
Hierochloe alpina	Sweet grass	Early seral	MSC, EMS	S, T	No	Winter hardy, erosion control
Kobresia myosuroides	-	Early and late seral	WB, MSC	S, T	No	Drought tolerant, winter hardy
Koleria macrantha	June grass	Early seral	MSC, EMS	S, T	Yes	Drought tolerant, winter hardy
Luzula spp.	Wood rush	Early and late seral	LMS, WM	S, T	No	Tolerates wet soil, winter hardy
Phleum alpinum	Alpine timothy	Early seral	MSC, EMS	S, T	Yes	Winter hardy, drought tolerant
Poa alpina	Alpine bluegrass	Early seral	MSC, EMS	S, T	Yes	Winter hardy, persistent
P. arctica	Arctic bluegrass	Early seral	MSC, EMS	S, T	No	Winter hardy, persistent
P. cusickii	Early bluegrass	Early seral	MSC, EMS	S, T	No	Drought tolerant
P. glauca	Glaucous bluegrass	Early seral	MSC, EMS	S, T	No	Winter hardy, drought tolerant
P. interior	Bluegrass	Early seral	MSC, EMS	S, T	No	Winter hardy
Trisetum spicatum	Spike trisetum	Early seral	MSC, EMS	S, T	No	Very drought tolerant, winter hardy, browse tolerant

[a] Recommended Site:

EWB - Extremely wind blown
WB - Wind blown
MSC - Minimal snow cover
EMS - Early melting snowbank
LMS - Late melting snowbank
PS - Perennial snowbank
WM - Wet Meadow

[b] Establishment Method

S - Seed
T - Transplant

Table 52. List of native forb species having potential for reclamation of alpine areas in Alberta.

Species	Common Name	Successional Stage	Recommended Site [a]	Establishment Method [b]	Commercially Available	Comments
Achillea millefolium	Common yarrow	Early seral	MSC, EMS	S	No	Drought tolerant, winter hardy, lower alpine
Anaphalis margaritacea	Pearly everlasting	Early and late seral	MSC, EMS	S	No	Winter hardy
Anemone spp.	Anemone	Early and late seral	EMS, LMS	S	No	Winter hardy, moist areas
Antennaria lanata	Wooly everlasting	Early and late seral	MSC, EMS	S, T	No	Drought tolerant, winter hardy, fine textured to stony soil
Artemisia norvegica	Sage	Early and late seral	MSC, EMS	S, T	No	Drought tolerant
Aster alpinus	Alpine aster	Early and late seral	MSC, EMS	S	No	Drought tolerant, lower alpine
Astragalus alpinus	Alpine milk vetch	Early seral	MSC, EMS	S	No	Tolerates soil creep, nitrogen fixer
Epilobium spp.	Fireweed	Early seral	MSC, EMS	S	Yes	Very winter hardy, gravel to stony soil
Eriogonum spp.	Umbrella plant	Early and late seral	MSC, EMS	S	No	Winter hardy, rocky slopes
Hedysarum alpinum	Alpine hedysarum	Early and late seral	MSC, EMS	S, T	No	Winter hardy, palatable for wildlife, nitrogen fixer
Lupinus argenteus	Silvery lupine	Early seral	MSC, EMS	S, T	No	Erosion control, nitrogen fixer
Oxytropis spp.	Loco-weed	Early and late seral	MSC, EMS	S, T	No	Drought tolerant, erosion control, nitrogen fixer
Penstemon spp.	Beard-tongue	Early and late seral	MSC, EMS	S	No	Drought tolerant
Phacelia sericea	Scorpion-weed	Early seral	MSC, EMS	S	No	Drought tolerant, rocky soils
Phlox hoodii	Moss phlox	Early and late seral	MSC, EMS	S	No	Winter hardy, drought tolerant
Polygonum bistortoides	Bistort	Early and late seral	MSC, EMS	T	No	Winter hardy, moist soils
Potentilla diversifolia	Cinquefoil	Early and late seral	MSC, EMS	S	No	Drought tolerant, winter hardy
Saxifraga spp.	Saxifrage	Early and late seral	MSC, EMS	S, T	No	Winter hardy, gravelly to stony soils
Sedum lanceolatum	Stonecrop	Early and late seral	MSC, EMS	S, T, C	No	Winter hardy, drought tolerant

continued . . .

Table 52. (Concluded).

Species	Common Name	Successional Stage	Recommended Site [a]	Establishment Method [b]	Commercially Available	Comments
Sibbaldia procumbens	Sibbaldia	Early and late seral	EMS, LMS	S, T	No	Tolerant of wet soils, winter hardy
Silene acualis	Moss campion	Early and late seral	MSC, EMS	S	No	Winter hardy, fine textured to stony soils
Vicia americana	Wild vetch	Early and late seral	MSC, EMS	S	Yes	Winter hardy, palatable for wildlife

[a] Recommended Site

EWB - Extremely wind blown
WB - Wind blown
MSC - Minimal snowcover
EMS - Early melting snowbank
LMS - Late melting snowbank
PS - Perennial snowbank
WM - Wet Meadow

[b] Establishment Method

S - Seed
T - Transplant
C - Cuttings

Table 53. List of native woody species having potential for reclamation of alpine areas in Alberta.

Species	Common Name	Successional Stage	Recommended Site [a]	Establishment Method [b]	Commercially Available	Comments
Alnus sinuata	Sitka alder	Early seral	LMS, WM	S, T	Yes	Winter hardy, erosion control, nitrogen fixer
Alnus tenuifolia	River alder	Early seral	LMS, WM	S, T	Yes	Lower alpine, tolerates wet soil, erosion control, nitrogen fixer
Arctostaphylos rubra	Alpine bearberry	Early and late seral	EMS, LMS	S, T	No	Winter hardy, persistent, berries palatable for wildlife
A. uva-ursi	Common bearberry	Early and late seral	MSC, EMS	S, T	Yes	Drought tolerant, erosion control, berries palatable for wildlife
Cassiope spp.	White mountain heather	Early and late seral	EMS, LMS	S, T, C	No	Tolerant of wet soil, erosion control
Dryas drummondii	Yellow mountain avens	Early seral	MSC	S	No	Drought tolerant, nitrogen fixer, erosion control, lower alpine, gravel soil
D. octapetala	White dryad	Early seral	WB, MSC	S, T	No	Winter hardy, nitrogen fixer, erosion control
Juniperus communis	Ground juniper	Late seral	MSC, EMS	S, T	Yes	Winter hardy, persistent, lower alpine
Larix lyallii	Lyall's larch	Early and late seral	EMS	S	No	Lower alpine, protected slopes, winter hardy, wildlife habitat
Phyllodoce glanduliflora and empetriformis	Yellow and purple mountain heather	Early and late seral	EMS, LMS	S, T, C	No	Tolerant of wet soil, erosion control
Picea engelmannii	Engelmann's spruce	Early and late seral	EMS	S	No	Lower alpine, shade tolerant, wildlife habitat
Pinus albicaulis	White-bark pine	Early seral	EMS	S	No	Lower alpine, drought tolerant, wildlife habitat
Pinus flexilis	Limber pine	Early seral	EMS	S	No	Lower alpine, drought tolerant, wildlife habitat
Potentilla fruticosa	Shrubby cinquefoil	Early seral	MSC, EMS	S, T	Yes	Winter hardy, erosion control, wildlife habitat
Rosa acicularis	Prickly rose	Early seral	MSC, EMS	S, T	Yes	Winter hardy, lower alpine, wildlife habitat
Rubus idaeus	Wild red raspberry	Early seral	MSC, EMS	S, T	Yes	Drought tolerant, lower alpine, wildlife habitat
Salix arctica and nivalis	Arctic and snow willow	Early and late seral	WB to WM	S, T, C	No	Very winter hardy, tolerant of wet soil, wildlife habitat

[a] Recommended Site

EWB - Extremely wind blown
WB - Wind blown
MSC - Minimal snowcover
EMS - Early melting snowbank
LMS - Late melting snowbank
PS - Perennial snowbank
WM - Wet Meadow

[b] Establishment Method

S - Seed
T - Transplant
C - Cuttings

Table 54. List of agronomic species having potential for reclamation of alpine areas in Alberta.

Species	Common Name	Successional Stage	Recommended Site [a]	Establishment Method [b]	Commercially Available	Comments
Agropyron intermedium var. Clarke	Intermediate wheatgrass	Early seral	MSC, EMS	S, T	Yes	Erosion control
A. trachycaulum var. Revenue	Slender wheatgrass	Early seral	MSC, EMS	S	Yes	Drought tolerant, erosion control
Agrostsis alba	Redtop	Early and late seral	MSC, WM	S, T	Yes	Winter hardy, erosion control
Alopecurus arundinaceus var. Garrison	Creeping foxtail	Early and late seral	LMS, WM	S	Yes	Winter hardy, tolerant of wet soil, erosion control
Astragalus cicer var. Cicer	Cicer milkvetch	Early and late seral	MSC, EMS	S	Yes	Winter hardy, nitrogen fixer, erosion control
Alopecurus pratensis	Meadow foxtail	Early seral	EMS, LMS	S	Yes	Winter hardy, tolerant of wet soil
Bromus inermis var. Polar, Manchar	Smooth brome	Early and late seral	MSC, EMS	S, T	Yes	Winter hardy, erosion control, persistent
Dactylis glomerata var. Tardus	Orchardgrass	Early and late seral	EMS, LMS	S, T	Yes	Winter hardy, erosion control, persistent
F. ovina var. Durar	Sheep fescue	Early and late seral	MSC, EMS	S, T	Yes	Very winter hardy, erosion control
F. rubra var. Arctared, Boreal	Creeping red fescue	Early and late seral	MSC, EMS	S, T	Yes	Very winter hardy, palatable for wildlife
Lolium perenne	Perennial rye grass	Early seral	EMS	S	Yes	Winter hardy, erosion control, short-lived
Phleum pratense var. Engmo, Climax	Timothy	Early seral	MSC, EMS	S	Yes	Rapid establishment, erosion control
Poa compressa var. Reubens	Canada bluegrass	Early and late seral	MSC, EMS	S, T	Yes	Drought tolerant, erosion control, persistent
P. pratensis var. Nugget, Troy	Kentucky bluegrass	Early and late	MSC, EMS	S, T	Yes	Winter hardy, erosion control, persistent

[a] Recommended Site

EWB - Extremely wind blown
WB - Wind blown
MSC - Minimal snowcover
EMS - Early melting snowbank
LMS - Late melting snowbank
PS - Perennial snowbank
WM - Wet Meadow

[b] Establishment Method

S - Seed
T - Transplant

A number of agronomic species have been developed which can be successfully established in the alpine in Alberta. The persistence of these species and production of viable seed will be variable depending upon site factors and the species used. When used in mixture with native species, the eventual attrition of the agronomic species should be regarded as a favourable event because of reduced competition for the seeded or invading native species.

6.4.2 Seeding Rates

Recommended seeding rates range from about 200 to 500 total viable seeds per m^2. On harsh sites (EWB, WB) seeding rates should be close to the higher rate, whereas more favourable sites (MSC, EMS, LMS, WM) should be seeded close to the lower rate. Seeding rates should be chosen so that there is adequate space for mature plants to establish without undue competition for light, moisture, and soil nutrients.

Seed germinability of native alpine species varies according to collection year and site, and this should be considered in determining seed application rates.

6.4.3 Seeding Methods

Various methods including hand seeding, broadcasting, and hydro-seeding have all been used successfully.

Knowledge of seed germination requirements of species is necessary to determine seeding methods, but this information is not readily available for alpine species. Many species have small seeds that cannot emerge from the soil if planted too deeply, whereas species with larger seeds may require deep planting to avoid desiccation during dormancy and seedling development. Some species such as *Carex paysonis* require light for germination. These species should be seeded on the soil surface separately following the planting and incorporation of other seeds on the site.

6.4.4 Timing

Seeding of alpine disturbances should be done only in the fall, particularly if native species are included in the mixture. Fall seeding allows for cold stratification over winter and germination under optimum

conditions during spring snowmelt. Seeding should be completed late enough to avoid seed germination and the breaking of dormancy. This will prevent frost damage to emerging tissues. Timing will be site- and year-specific therefore exact prescriptions can not be made.

6.4.5 Fertilizer Application

In general, fertilizer applications are considered essential for successful and rapid establishment of plant cover on alpine disturbances. The rate of application and composition of the fertilizer required will vary from site to site. Soil analyses and/or a soil bioassay should be undertaken to determine site specific nutrient requirements. Nitrogen and phosphorus are usually the most limiting elements.

One method that was found to be effective was to apply fertilizer in both the first and early in the second or third growing season and then wait until the stand becomes nutrient deficient before applying another application. An additional application in the fifth or sixth growing year might be necessary. The maintenance application should be of the same formulation as that applied originally. Continued high application rates of fertilizer may favour the high growth rate-adapted and high nutrient-adapted species and result in reduced rates of invasion by native species, and natural succession.

Initial fertilizer application may be applied just prior to seeding and should be incorporated to a depth of 3 to 5 cm so that it will be available as the plants develop. Subsequent applications early in the growing season will minimize losses through leaching and obtain the maximum benefit from the short growing season.

6.4.6 Transplanting Individual Plants

Transplanting native plants is expensive because of labour requirements but has proven to be an effective method of revegetating small areas. Survival rates are generally high. However, differences in microsites need to be closely observed and matched with vegetation patterns to indicate the proper species for transplanting to given sites. Transplanting success tends to be lower in the exposed fellfield sites and higher in the snowbed and wet meadow sites. Species with fibrous roots do better than plants with rhizo-

matous roots, and these do better than plants with rootstocks or corms. Naturally wide ranging species tend to be the best transplanters.

Alpine plants grown in greenhouse containers can also be successfully transplanted. This technique offers potential for large scale production with improved planting and economic efficiencies. Tussocks of some alpine grasses can be successfully subdivided into single tillers which can be transplanted. On particularly harsh sites where conventional seeding methods are not practical, transplanting may be the best revegetation technique available.

6.4.7 Transplanting Sod

Transplanting alpine vegetation sod is also a successful method for revegetating small areas. As for transplanting individual plants, microsites must be matched even when moving sod short distances along a moisture gradient.

Prompt placement of the sod in the new location is necessary for good results. If sod needs to be stored before replacement, it should be kept in a cool moist location and/or covered with burlap fabric to preserve sod moisture.

Sod should be replaced at a level slightly above the adjacent ground levels. If replaced below the adjacent ground level, plants may be buried by soil washed into the depressions. If placed above the adjacent ground level the edges of the replaced sod will dry out.

Transplanting sod has the disadvantage of causing damage to the area used as a source of donor plants. The source of sod clumps would best be restricted to minimum snow cover (MSC) and wet meadow (WM) sites which are protected by winter snow cover and would likely be revegetated most easily. Alternatively, sod clumps should be salvaged prior to disturbance.

6.4.8 Maintenance

After an alpine disturbance has been seeded and/or planted, the site may need ongoing maintenance to ensure revegetation success. Maintenance may include refertilization, reseeding, monitoring and other activities to ensure that the site remains reclaimed at a level that maintains site capability. This should be part of any reclamation plan for the alpine.

Use of seeded areas should probably be restricted for at least five growing seasons to allow for plants to become fully established.

6.5 MONITORING

A program of monitoring is recommended to ensure that plants are developing and that the soil surface is stabilizing. The following parameters can be measured at regular intervals to monitor progress:

1. Plant Density and Cover. This can provide information on plant growth and persistence, and an indication of the effectiveness of vegetation in providing an erosion controlling cover.
2. Flowering and Formation of Viable Seed. This provides information on those species that can reproduce on a given site and are likely to persist in the medium to long-term.
3. Invasion of Native Plants. The density of native plants should be assessed every couple of years to determine the progress of succession towards a native plant community.
4. Soil Nutrient Status. Measurement of soil organic matter and soil nutrient status will provide an indication of soil development and the need for maintenance fertilization.

6.6 INFORMATION REQUIREMENTS FOR EFFECTIVE RECLAMATION PLANNING

6.6.1 Baseline Information

The information required for reclamation planning is dependent on the type of development activity and the associated impacts. A brief description of the information needs for different development activities in the alpine is given in the following sections.

6.6.1.1 Microclimate research. Topography, through its control of snow distribution, is the most important factor in controlling the distribution of plants and soils in the alpine tundra. Information of the influence of development activities on microclimate is essential for effective reclamation planning. For example, information is needed on the impact of mine dump configuration on microclimate and snow accumulation, and the resulting influence on revegetation and hydrology at the site.

6.6.1.2 Vegetation gradients. Environmental gradients have a large influence on plant distribution. Vegetation baselines can provide information about the best adapted combination of species for a given set of environmental conditions. The data can also identify areas that are susceptible to disturbance, endangered species, and the relationship of wildlife to environmental gradients.

6.6.1.3 Soils. A detailed soil survey is necessary to determine soils suitable for salvage. It will also provide information on areas susceptible to mass wasting and wind erosion, and identify areas of soil creep, frost churning, permafrost, and frost induced earth hummocks.

6.6.1.4 Hydrology. Reclamation planning needs to include provision for a detailed drainage and erosion control scheme. The hydrologic regime of the development area needs to be assessed to determine possible impacts and to assist in designing sediment control structures.

6.6.2 Reclamation Research

6.6.2.1 Characterization of spoil properties. Spoil should be analyzed to determine physical and chemical properties as they affect plant growth. Little is known about the nutrient requirements of native plant species. Bioassay experiments using native plant species can be usefully employed. This technique has been used with good success to determine the most effective methods for amending mine spoil from a disturbed alpine site. There was good agreement between the greenhouse bioassay results and subsequent field trials in the alpine.

6.6.2.2 Soil selection criteria. The rate of colonization and re-establishment of alpine plants on disturbed sites appears to be influenced by:

1. availability of soil water,
2. soil chemistry, and
3. age of the disturbance.

Topography and soil structure may also be important. Research is needed to assess those soil properties which are most important for plant

establishment and growth in the alpine. Frost heave caused by the formation of needle-ice is one of the most limiting factors to revegetation in the alpine. Selection criteria need to make provision for susceptibility of various soils to the formation of needle-ice.

6.6.2.3 Species selection. Very little is known about the performance of individual native plant species on disturbed sites in the alpine in Alberta. Only a small proportion of alpine plants are active colonizers and many of these are limited to specific sites. Field trials are required to select plant species appropriate for revegetation of particular sites. In particular, information is needed on:

1. nutrient requirements,
2. drought tolerance,
3. germination and establishment requirements,
4. propagation of native legumes (nitrogen fixers), and
5. propagation of woody species by cuttings.

6.6.2.4 Intensity of reclamation effort. Plant cover that meets short-term goals may not be appropriate for meeting long-term goals. Natural succession in the alpine is very slow. The level and intensity of site treatment needed to achieve long-term revegetation goals may substantially exceed minimal requirements for initial stand establishment. Research is needed on alpine plant succession and cultural methods which can enhance the rate of succession.

6.7 RESEARCH NEEDS

The following is a list of research needs which have been noted by various researchers in the literature.

6.7.1 Impacts

1. Carrying capacities of different vegetation types for human and wildlife use.
2. Recovery rates of various vegetation types after various impacts.

6.7.2 Plant Adaptations

1. Micro-environmental research to define the most important limiting factors for plant growth.
2. Physiological tolerance limits of individual species including heavy metal toxicity and mineral deficiencies.
3. Growth responses of individual species to specific nutrient levels.
4. Characteristics and long-term interactions of mycorrhizal and nitrogen fixing symbionts with alpine plants.
5. Water relations and drought stress in alpine plants.
6. Structure and growth rates of alpine plant root systems.

6.7.3 Species Selection

1. Selection and breeding programs for appropriate native species.
2. Breeding and evaluation of new varieties of commonly used agronomic species.
3. Identification of nitrogen fixing species and ecotypes of high altitude legumes.
4. Ability of different legumes to provide nitrogen to associated species.
5. Observations on different clonal systems in alpine plants.
6. Plant colonization studies to identify adapted native species.
7. Selection of native grass species which are suitable for subdivision into individual tillers and rates of survival, and growth of transplanted tillers.

6.7.4 Revegetation

1. Definition of what site factors are critical for seedling establishment for individual species in different alpine environments.
2. Germination requirements for native plant species.
3. Development of specialized planting techniques such as sodding, sprigging, and transplanting.
4. Influence of climate conditions on vegetation growth. Variation in climatic conditions from year to year can have a marked influence on vegetation growth.
5. Propagation techniques for alpine forbs, shrubs, and grasses.
6. Development of appropriate inocula for native alpine legumes.
7. Effectiveness of broadcasting, aerial seeding, and hydroseeding techniques on different sites.
8. Identification of optimum species mixes for various landscape types.

6.7.5 Fertilization

1. Types of fertilizers best suited for alpine plants.
2. Fertilizer application rates and length of effectiveness.
3. Influence of fertilizer applications on floristic composition, and rates of invasion of native species and natural succession.
4. Suitability of slow release fertilizers.

6.7.6 Soils and Surface Amendments

1. Fertility of alpine soils.
2. Susceptibility of different soils to needle-ice.
3. Effectiveness of different mulches to reduce needle-ice activity.
4. Effectiveness of different mulches for erosion control in the alpine.
5. Effectiveness of soil top dressing on plant establishment and growth.
6. Effectiveness of seed terraces on revegetation and erosion control.

7. Effectiveness of different cultivation methods, i.e., harrowing, disking, ploughing on revegetation success.
8. Soil salvage techniques.
9. Effect of various soil layers and mixes of soil layers on plant establishment and growth.

6.7.8 Equipment

1. Equipment for topsoil salvage on steep slopes.
2. Seeding equipment for steep slopes.
3. Mulching techniques and equipment on steep slopes.

7. GLOSSARY

Ablation	The breakdown of glaciers and rocks, or the melting and evaporation of ice and snow.
Acid Soil	Soil of pH less than 7.0.
Adaptation	Change in an organism due to natural selection that enables it to be better suited to its environment.
Advection	Transport of an atmospheric property such as heat or moisture by the atmosphere's velocity field.
Albedo	The ratio of electromagnetic radiation reflected by a surface to that absorbed, usually expressed as a percentage.
Alpine	Pertains to those portions of mountains above the upper limit of tree growth and to the organisms living there.
Alpine Soil	Mountain soil occurring above the upper limit of tree growth.
Alpine Desert	Portions of mountains above the upper limit of tree growth where abundant moisture may be present, but unavailable because of physiological dryness due to extreme cold.
Alpine Grassland	Mountain regions above the upper limit of tree growth which may eventually support grass-like vegetation under present climatic conditions.
Alpine Meadow	A high-altitude area of low herbaceous vegetation dominated by species of grasses, sedges and forbs.
Alpine Tundra	A grassland area located above the upper limit of tree growth in mountain regions.
Alluvium	Material such as clay, silt, sand and gravel recently deposited by rivers and streams.
Available Water	The portion of water in a soil that can be readily absorbed by plant roots.
Bedrock	Solid rock that either underlies soil and weathered rock, or is exposed at the ground surface.
Boulder Fields	Fields of large angular boulders covering otherwise exposed bedrock.

Brunisolic — A soil order of sufficient development to exclude it from the Regosolic order, but without sufficient development to include it in any other order. These soils develop under various climates and vegetation, and are frequently characterized by a reddish colour.

Bulbil — A small bulb or modified bud used for vegetative reproduction. Plants having bulbils are bulbilliferous.

Catena — A sequence of soils of about the same age, derived from similar parent materials, and occurring under similar climatic conditions, but of unlike characteristics due to variations in relief and drainage.

Circles (non-sorted) — Patterned ground comprised of peat rings, tussock rings or stones that have a non-sorted appearance due to the absence of a stone border.

Circles (sorted) — Similar to non-sorted circles except sorted circles have a distinct stone border.

Climatic Snow Line — The altitude above which snow accumulates indefinitely on flat surfaces exposed to sun and wind.

Clone — All asexually derived individuals produced from a single sexually produced individual.

Coarse Fragments — Rock or mineral particles greater than 2.0 mm in diameter.

Colloid — Mineral or organic particles smaller than 0.002 mm that have properties determined by surface forces.

Colluvial Slope — Sloping land at the foot of steep hills or mountains made up of deposits of unconsolidated material that has been moved over short distances by gravity, water, or both and includes talus material and local alluvium.

Compost — Moist organic remains, or mixtures of organic remains and soil to which mineral fertilizers may be added, and which have been piled and allowed to decompose (artificial manure).

Congelifluction — Progressive and lateral earth flow occurring under conditions of perennially frozen ground.

Congeliturbation — Frost action that causes stirring, thrusting and heaving of the earth's mantle, or massive lateral soil movements.

Corm — A solid but bulb-like underground stem, in which food is accumulated, usually in the form of starch.

Creep	Slow mass movement of soil and soil material down rather steep slopes primarily under the influence of gravity, but aided by saturation with water and by alternate freezing and thawing.
Cryopedogenic Processes	The freeze-thaw processes in soil formation.
Cryoturbation	Frost action including frost heaving.
Dispersal	The spreading of reproductive plant parts from one place or area to another.
Diurnal Needle-Ice	Dense bundles of needle-like crystals beneath the ground surface and at right angles to it caused by daily fluctuations in temperature.
Dryas Island	A circular community, mainly of *Dryas* spp. surrounded by gravel and cobbles.
Dystric Brunisol	A great group of soils in the Brunisolic order characterized by mull Ah horizons less than 5 cm thick, and an acidic pH.
Earth Hummocks	Low rounded knobs of fine material covered by a tight mass of moss, grass and scrubby plants
Ecosystem	A complex of living organisms and their environment, linked by energy flows and material cycling.
Ecotone	A transition zone of vegetation between two communities, which has characteristics of its own and of both types of adjacent vegetation.
Ecotype	A local ecological race adapted through natural selection to a particular habitat.
Erosion	The wearing away of the land surface by running water, wind, ice, other geological agents, activities of man or animals, and including such processes as gravitational creep.
Eutric Brunisol	A great group of soils in the Brunisolic order having mull Ah horizons less than 5 cm thick and a relatively high degree of base saturation.
Evapotranspiration	The process of evaporation of water from a soil surface together with transpiration by plants.
Exchangeable Bases	Cations or bases adsorbed onto soil colloids.

Fellfield	Rocky stands, consisting of a large proportion of boulders with lichens, mosses, cushion plants and lower forms of vascular plants, located on exposed summits and ridges or in saddles through which wind is funnelled.
Felsenmeer	Extensive accumulations of predominantly angular, boulder-sized, frost-shattered rocks on horizontal and gently sloping terrain.
Fertilizer	Any organic or inorganic material of natural or synthetic origin that is added to soil to supply certain elements essential to plant growth.
Field Capacity	The amount of water retained in the soil after the soil has been saturated and free drainage has practically ceased.
Frost	A light, feathery, crystalline ice deposit caused by the condensation of water vapour on objects whose temperatures are below freezing.
Frost Action	A weathering process caused by repeated freeze-thaw cycles.
Frost Boil	Domed areas of bare, light-coloured soil which have been sufficiently disturbed by frost action to prevent plant colonization.
Frost Churning	See congeliturbation.
Frost Heaving	The lifting of a soil surface caused by ice crystals underneath the soil. Exposed, fine-textured soils are particularly susceptible to frost heaving.
Frost Hummock	See earth hummock.
Frost Line	The maximum depth to which the ground becomes frozen; it may be given for a particular winter, for the average of several winters, or for the extreme depth ever reached.
Frost Scars	Small patches of bare soil lacking the domed appearance of frost boils, that are either barren or partially covered by lichens, and that result from frost stirring or ice crystallization processes.
Gleysation	A soil-forming process under conditions of poor drainage resulting in reduction of iron and other elements and in grey colours and mottles.
Gleyed Soil	A soil affected by gleysation.

Gleysol	A great group of soils in the Gleysolic order characterized by an absent or thin Ah horizon underlain by mottled gray or brownish gleyed material.
Habitat	The natural environment of an organism.
Hardiness	The ability to withstand severe climates, especially frost during the growing season.
Hemicryptophyte	A plant characterized by having its lateral growth buds located in the soil surface.
Horizon, Soil	A layer of soil or soil material approximately parallel to the land surface distinguishable from adjacent layers by colour, structure, consistence, chemical, biological and mineralogical composition.
Hummocks	Refers to either earth hummocks or piles of ice on an ice field.
Ice Lenses	Small lenses of ice formed by frozen soil water.
Ice Wedge Polygon	A polygonal-shaped ground feature formed by bordering wedge-shaped pieces of clear ice.
Ice Wedge	Wedge-shaped formations of clear ice existing near soil surfaces.
Improvement, Soil	Increasing a soil's capability to sustain plant growth by drainage and irrigation, or through the addition of various soil amendments such as fertilizers.
Infiltration	Downward water movement into the soil.
Inoculation	The artificial introduction of micro-organisms into a habitat or their introduction into a culture medium.
Inversion	A meterological term used to describe phenomena that result in a reversal of the normal decrease of temperature with altitude.
Krummholz	Shrubby, stunted, deformed trees located at the limit of tree growth on mountains and which tend to sprawl in the direction of the prevailing wind.
Landslide	Rapid movement of soil, rock, or debris down a slope as a result of gravity, or gravity and water when the material is saturated.

Layering Vegetative reproduction, especially by conifers at the limit of tree growth at high altitudes where the lowest boughs touching the ground take root to produce another tree.

Leaching The removal of soil material in suspension or in solution by the downward or lateral percolation of water.

Lipid A water insoluble fat or fat-like compound.

Manure Animal excreta in various stages of decomposition.

Mass Movement Movements of large portions of the land surface caused by either water saturation or water saturation and frost action. Mass movements include landslides, mud slides, creep, congeliturbation and solifluction.

Mass Wasting A general term used to describe the movement of large masses of earth material by gravity either slowly or quickly from one place to another.

Microflora Plants that are too small to be distinguishable without the aid of a microscope. Plants in this category include algae, bacteria, and fungi.

Mine Dump Area covered with overburden and other waste materials from ore and coal mines, quarries and smelters, and usually having little or no vegetative cover prior to reclamation.

Mineralization The conversion of an element from an organic form to an inorganic state as a result of microbial decomposition.

Mottles Spots or blotches of different colour or shades of colour found in imperfectly drained soils.

Mottling Formation or presence of soil mottles.

Muck Soil An organic soil consisting of highly decomposed material.

Mulch Any material such as straw, sawdust, woodchips, leaves or loose soil that is spread on the soil surface to protect the soil and plant roots from the effects of raindrops, wind erosion, soil crusting, freezing and evaporation.

Mycorrhiza The mutually beneficial association of fungi with the roots of seed plants.

Needle-Ice Dense bundles of needle-like ice crystals beneath the ground surface, and at right angles to it.

Nets, Non-sorted	Patterned ground that is neither distinctly circular or polygonal and has a non-sorted appearance because it lacks a stone border.
Nets, Sorted	Similar to non-sorted nets but characterized by a stone border which gives them a sorted appearance.
Nitrogen Fixation	The conversion of elemental nitrogen to forms that allow for ready uptake by plants.
Nival Climate	A term used to describe the climate of areas characterized by maintaining the same snow cover for two or more years.
Nival Zone	The zone of perennial snow.
Nivation	Erosion caused by snow action, or frost action and mass-wasting beneath a snowbank.
Organic	An order of soils that have developed dominantly from organic deposits.
Organic Matter, Soil	The organic part of the soil including plant and animal remains at various decomposition stages, cells and tissues of soil organisms, and substances generated by these organisms.
Parent Material	Unconsolidated mineral or organic material from which soils develop.
Patterned Ground	Ground surfaces characterized by more or less obvious patterns in the shape of circles, polygons, nets, steps or stripes resulting from below ground frost action.
Percolation	The downward flow of water in saturated or nearly saturated soil.
Periglacial	Areas, conditions, processes and deposits adjacent to glacier margins.
Permafrost	Permanently frozen ground.
Photosynthesis	The food-making process whereby green plants and other autotrophs covert sunlight into chemical energy.
Podzolic	A soil order in which B horizons contain organic matter (mainly fluvic acid) and accumulations of aluminum and iron.
Pore Space	Spaces between soil particles in a volume of soil.
Pores, Soil	The part of the bulk volume of soil not occupied by soil particles.

Porosity	The volume percentage of the total bulk not occupied by solid particles.
Propagule	A part of a plant that implants a new individual.
Regolith	The unconsolidated mantle of weathered rock and soil material overlying solid rock.
Regosolic	An order of soils having no horizon development or development of the A and B horizons insufficient to meet the requirements of the other orders.
Respiration	The process by which organisms convert food into food energy for use in vital activities.
Rhizobia	Small heterotrophic bacteria of the genus *Rhizobium* that fix atmospheric nitrogen through the use of nodules on the roots of leguminous plants.
Rock Field	Synonymous with fellfield.
Rock Flour	Finely ground rock particles, primarily silt-sized formed by the action of a glacier grinding rocks in its base as it moves forward.
Rock Glaciers	A glacier containing numerous angular boulders that is tongue-shaped and originates in cirques or other steep-walled amphitheaters.
Runoff	The portion of the total precipitation on an area that flows away through stream channels. Surface runoff does not enter the soil. Groundwater runoff or seepage flow from groundwater enters the soil before reaching the stream.
Scarification	A term that applies either to seed coat abrasion to promote germination, or to seedbed preparation to make a site more amenable to plant growth.
Scree	An unstratified deposit of gravel, boulders, sand and finer material which has been transplanted by a glacier.
Snowfield	An area or mass of snow that remains throughout the summer.
Snowpatch	An area in which snow melts late in the year and where vegetaion is characteristic of such a site or is lacking.
Solifluction	The flow of saturated soil downslope over rock or frozen ground, and the subsequent sorting of the debris on level ground, especially under conditions of alternate freezing and thawing.

Solifluction Lobe	Tongue-like mass of solifluction debris commonly with steep fronts and a relatively gentle upper surface.
Spalling	Breaking off in layers which are parallel to a surface.
Steps, Non-sorted	Ground which has a visually indistinct step-like form, since it lacks a downslope border of stones.
Steps, Sorted	Similar to non-sorted steps except more visually obvious due to the presence of a downslope border of stones.
Stone Nets	A ring or polygon of stones surrounding a central area of fine debris in a bouldery soil region.
Stone Stripes	Bands of fine rock debris alternating with channels filled with coarse rock fragments oriented parallel to the slope.
String Bog	Narrow parallel ridges of sphagnum separated by pools of standing water.
Subalpine	An area located altitudinally between the treeless alpine zone and the closed montane forest of lower elevations, and characterized by discontinuous tree growth.
Talus	A sloping heap of loose rock fragments lying at the foot of a cliff or steep slope.
Terrace	A nearly level, somewhat narrow plain, existing naturally along rivers, lakes or seas or created artificially to reduce erosion by overland runoff.
Texture, Soil	The relative proportions of sand, silt or clay contained in a soil sample.
Till	An unstratified, non-sorted deposit of gravel, boulders, sand and finer materials which has been transported by a glacier.
Till, to	To plow and prepare for seeding; to cultivate the soil.
Timberline	The boundary between subalpine forest and alpine meadow which may imply the upper altitudinal edge of continuous forest, the altitude of the highest tree, or the midpoint between these extremes.
Topsoil	The uppermost part of the soil normally affected by tillage, and used to topdress surface disturbances in order to promote plant germination.
Tundra	A level of undulating treeless plain and the vegetation thereon, characterized by black muck soils and permanently frozen subsoil.

Tundra Soil Any soil in the tundra region.

Tussocks A grouping of tufted plants that typically have numerous stems originating from a single crown.

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APPENDIX A

LIST OF CONTACTS

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APPENDIX B
RECLAMATION RESEARCH REPORTS

1. **RRTAC 79-2: Proceedings: Workshop on Native Shrubs in Reclamation. P.F. Ziemkiewicz, C.A. Dermott and H.P. Sims (Editors). 104 pp. No longer available.**

The Workshop was organized as the first step in developing a Native Shrub reclamation research program. The Workshop provided a forum for the exchange of information and experiences on three topics: propagation; outplanting; and, species selection. Seven papers and the results of three discussion groups are presented.

2. **RRTAC 80-1: Test Plot Establishment: Native Grasses for Reclamation. R.S. Sadasivaiah and J. Weijer. 19 pp. No longer available.**

The report details the species used at three test plots in Alberta's Eastern Slopes (one at Caw Creek Ridge and two at Cadomin). Site preparation, experimental design, and planting method are also described.

3. **RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp. $10.00**

This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

4. **RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi and H.F. Regier (Editors). 160 pp. $10.00**

Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

5. **RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. L.E. Watson, R.W. Parker and D.F. Polster. 2 vols, 541 pp. No longer available; replaced by RRTAC 89-4.**

Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their suitability for use in reclamation. Range maps, growth habit, propagation, tolerance, and availability information are provided.

6. **RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp. $10.00**

This survey is an update of a report prepared in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

7. **RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stein, R. Leitch and G. Lutwick (Editors). 253 pp. $10.00**

Presents nine technical papers on the chemical, physical, and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites, and use of ash as a soil amendment. Workshop discussions and summaries are also included.

8. **RRTAC 82-1: Land Surface Reclamation: An International Bibliography. H.P. Sims and C.B. Powter. 2 vols, 292 pp. $10.00**

Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system (in a SPIRES database called RECLAIM). Vol. 2 comprises the keyword index and computer access manual.

9. **RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp. $5.00**

This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981, are available in the Alberta Environment Library.

10. **RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp. No longer available**

Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of field trials.

11. **RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp. No longer available.**

Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop production.

12. **RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz (Editor). 123 pp. $10.00**

Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics, and resulting water quality. Mitigative measures and priorities were also discussed.

13. **RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Techman Engineering Ltd. 124 pp. No longer available.**

This is a review and analysis of information on planting stock quality, rearing techniques, site preparation, planting, and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

14. **RRTAC 84-1: Land Surface Reclamation: A Review of the International Literature. H.P. Sims, C.B. Powter and J.A. Campbell. 2 vols, 1549 pp. $20.00**

Nearly all topics of interest to reclamationists including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

15. **RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp. $10.00**

This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

16. **RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

17. **RRTAC 84-4: Soil Microbiology in Land Reclamation. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser and J.C. Zak. 2 vols, 676 pp. $10.00**

This is a collection of five reports dealing with re-establishment of fungal decomposers and mycorrhizal symbionts in various amended spoil types.

18. **RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz (Editor). 416 pp. $10.00**

Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling, shrub propagation and establishment are presented.

19. **RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

20. **RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp. $10.00**

The report examines the critical issue of settling pond design, and sizing and alternative technologies. The study was co-funded with The Coal Association of Canada.

21. **RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp. No longer available.**

Reconstructed soils representing different materials handling and replacement techniques were characterized, and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

22. **RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp. $5.00**

In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

23. **RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp. $10.00**

This report summarizes the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establish a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

24. **RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 71 pp. $10.00**

This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

25. **RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp. $5.00**

The report deals with the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is in the Battle River Mining area in east-central Alberta.

26. **RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp. $5.00**

This report evaluates the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

27. **RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

28. **RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp. No longer available.**

This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed. The study was co-funded with The Coal Association of Canada.

29. **RRTAC 87-1: Disposal of Drilling Wastes. L.A. Leskiw, E. Reinl-Dwyer, T.L. Dabrowski, B.J. Rutherford and H. Hamilton. 210 pp. No longer available.**

Current drilling waste disposal practices are reviewed and criteria in Alberta guidelines are assessed. The report also identifies research needs and indicates mitigation measures. A manual provides a decision-making flowchart to assist in selecting methods of environmentally safe waste disposal.

30. **RRTAC 87-2: Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills. A.W. Fedkenheuer, L.J. Knapik and D.G. Walker. 174 pp. $10.00**

This report reviews current reclamation practices with regard to site and soil reconstruction and re-establishment of biological productivity. It also identifies research needs in the Mountain-Foothills area. The study was co-funded with The Coal Association of Canada.

31. **RRTAC 87-3: Gel and Saline Drilling Wastes in Alberta: Workshop Proceedings. D.A. Lloyd (Compiler). 218 pp. No longer available.**

Technical papers were presented which describe: mud systems used and their purpose; industrial constraints; government regulations, procedures and concerns; environmental considerations in waste disposal; and toxic constituents of drilling wastes. Answers to a questionnaire distributed to participants are included in an appendix.

32. **RRTAC 87-4: Reclamation Research Annual Report - 1986. 50 pp. $5.00**

This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

33. **RRTAC 87-5: Review of the Scientific Basis of Water Quality Criteria for the East Slope Foothills of Alberta. Beak Associates Consulting Ltd. 46 pp. $10.00**

The report reviews existing Alberta guidelines to assess the quality of water drained from coal mine sites in the East Slope Foothills of Alberta. World literature was reviewed within the context of the East Slopes environment and current mining operations. The ability of coal mine operators to meet the various guidelines is discussed. The study was co-funded with The Coal Association of Canada.

34. **RRTAC 87-6: Assessing Design Flows and Sediment Discharge on the Eastern Slopes. Hydrocon Engineering (Continental) Ltd. and Monenco Consultants Ltd. 97 pp. $10.00**

The report provides an evaluation of current methodologies used to determine sediment yields due to rainfall events in well-defined areas. Models are available in Alberta to evaluate water and sediment discharge in a post-mining situation. SEDIMOT II (Sedimentology Disturbed Modelling Techniques) is a single storm model that was developed specifically for the design of sediment control structures in watersheds disturbed by surface mining and is well suited to Alberta conditions. The study was co-funded with The Coal Association of Canada.

35. **RRTAC 87-7: The Use of Bottom Ash as an Amendment to Sodic Spoil. S. Fullerton. 83 pp. No longer available.**

The report details the use of bottom ash as an amendment to sodic coal mine spoil. Several rates and methods of application of bottom ash to sodic spoil were tested to determine which was the best at reducing the effects of excess sodium and promoting crop growth. Field trials were set up near the Vesta mine in East Central Alberta using ash readily available from a nearby coal-fired thermal generating station. The research indicated that bottom ash incorporated to a depth of 30 cm using a subsoiler provided the best results.

36. **RRTAC 87-8: Waste Dump Design for Erosion Control. R.G. Chopiuk and S.E. Thornton. 45 pp. $5.00**

This report describes a study to evaluate the potential influence of erosion from reclaimed waste dumps on downslope environments such as streams and rivers. Sites were selected from coal mines in Alberta's mountains and foothills, and included resloped dumps of different configurations and ages, and having different vegetation covers. The study concluded that the average annual amount of surface erosion is minimal. As expected, erosion was greatest on slopes which were newly regraded. Slopes with dense grass cover showed no signs of erosion. Generally, the amount of erosion decreased with time, as a result of initial loss of fine particles, the formation of a weathered surface, and increased vegetative cover.

37. **RRTAC 87-9: Hydrogeology and Groundwater Chemistry of the Battle River Mining Area. M.R. Trudell, R.L. Faught and S.R. Moran. 97 pp. No longer available.**

This report describes the premining geologic conditions in the Battle River coal mining area including the geology as well as the groundwater flow patterns, and the groundwater quality of a sequence of several water-bearing formations extending from the surface to a depth of about 100 metres.

38. **RRTAC 87-10: Soil Survey of the Plains Hydrology and Reclamation Project - Battle River Project Area. T.M. Macyk and A.H. MacLean. 62 pp. plus 8 maps. $10.00**

The report evaluates the capability of post-mining landscapes and assesses the changes in capability as a result of mining, in the Battle River mining area. Detailed soils information is provided in the report for lands adjacent to areas already mined as well as for lands that are destined to be mined. Characterization of the reconstructed soils in the reclaimed areas is also provided. Data were collected from 1979 to 1985. Eight maps supplement the report.

39. **RRTAC 87-11: Geology of the Highvale Study Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 78 pp. $10.00**

The report is one of a series that describes the geology, soils and groundwater conditions at the Highvale Coal Mine study site. The purpose of the study was to establish a summary of site geology to a level of detail necessary to provide a framework for studies of hydrogeology and reclamation.

40. **RRTAC 87-12: Premining Groundwater Conditions at the Highvale Site. M.R. Trudell and R. Faught. 83 pp. $10.00**

This report presents a detailed discussion of the premining flow patterns, hydraulic properties, and isotopic and hydrochemical characteristics of five layers within the Paskapoo Geological Formation, the underlying sandstone beds of the Upper Horseshoe Canyon Formation, and the surficial glacial drift.

41. **RRTAC 87-13: An Agricultural Capability Rating System for Reconstructed Soils. T.M. Macyk. 27 pp. $5.00**

This report provides the rationale and a system for assessing the agricultural capability of reconstructed soils. Data on the properties of the soils used in this report are provided in RRTAC 86-2.

42. **RRTAC 88-1: A Proposed Evaluation System for Wildlife Habitat Reclamation in the Mountains and Foothills Biomes of Alberta: Proposed Methodology and Assessment Handbook. T.R. Eccles, R.E. Salter and J.E. Green. 101 pp. plus appendix. $10.00**

The report focuses on the development of guidelines and procedures for the assessment of reclaimed wildlife habitat in the Mountains and Foothills regions of Alberta. The technical section provides background documentation including a discussion of reclamation planning, a listing of reclamation habitats and associated key wildlife species, conditions required for development, recommended revegetation species, suitable reclamation techniques, a description of the recommended assessment techniques and a glossary of basic terminology. The assessment handbook section contains basic information necessary for evaluating wildlife habitat reclamation, including assessment scoresheets for 15 different reclamation habitats, standard methodologies for measuring habitat variables used as assessment criteria, and minimum requirements for certification. This handbook is intended as a field manual that could potentially be used by site operators and reclamation officers. The study was co-funded with The Coal Association of Canada.

43. **RRTAC 88-2: Plains Hydrology and Reclamation Project: Spoil Groundwater Chemistry and its Impacts on Surface Water. M.R. Trudell (Compiler). 135 pp. $10.00**

Two reports comprise this volume. The first "Chemistry of Groundwater in Mine Spoil, Central Alberta," describes the chemical make-up of spoil groundwater at four mines in the Plains of Alberta. It explains the nature and magnitude of changes in groundwater chemistry following mining and reclamation. The second report, "Impacts of Surface Mining on Chemical Quality of Streams in the Battle River Mining Area," describes the chemical quality of water in streams in the Battle River mining area, and the potential impact of groundwater discharge from surface mines on these streams.

44. **RRTAC 88-3: Revegetation of Oil Sands Tailings: Growth Improvement of Silver-berry and Buffalo-berry by Inoculation with Mycorrhizal Fungi and N_2-Fixing Bacteria. S. Visser and R.M. Danielson. 98 pp. $10.00**

The report provides results of a study: (1) To determine the mycorrhizal affinities of various actinorrhizal shrubs in the Fort McMurray, Alberta region; (2) To establish a basis for justifying symbiont inoculation of buffalo-berry and silver-berry; (3) To develop a growing regime for the greenhouse production of mycorrhizal, nodulated silver-berry and buffalo-berry; and, (4) To conduct a field trial on reconstructed soil on the Syncrude Canada Limited oil sands site to critically evaluate the growth performance of inoculated silver-berry and buffalo-berry as compared with their un-inoculated counterparts.

45. **RRTAC 88-4: Plains Hydrology and Reclamation Project: Investigation of the Settlement Behaviour of Mine Backfill. D.R. Pauls (compiler). 135 pp. $10.00**

This three part volume covers the laboratory assessment of the potential for subsidence in reclaimed landscapes. The first report in this volume, "Simulation of Mine Spoil Subsidence by Consolidation Tests," covers laboratory simulations of the subsidence process particularly as it is influenced by resaturation of mine spoil. The second report, "Water Sensitivity of Smectitic Overburden: Plains Region of Alberta," describes a series of laboratory tests to determine the behaviour of overburden materials when brought into contact with water. The report entitled "Classification System for Transitional Materials: Plains Region of Alberta," describes a lithological classification system developed to address the characteristics of the smectite rich, clayey transition materials that make up the overburden in the Plains of Alberta.

46. **RRTAC 88-5: Ectomycorrhizae of Jack Pine and Green Alder: Assessment of the Need for Inoculation, Development of Inoculation Techniques and Outplanting Trials on Oil Sand Tailings. R.M. Danielson and S. Visser. 177 pp. $10.00**

The overall objective of this research was to characterize the mycorrhizal status of Jack Pine and Green Alder which are prime candidates as reclamation species for oil sand tailings and to determine the potential benefits of mycorrhizae on plant performance. This entailed determining the symbiont status of container-grown nursery stock and the quantity and quality of inoculum in reconstructed soils, developing inoculation techniques and finally, performance testing in an actual reclamation setting.

47. **RRTAC 88-6: Reclamation Research Annual Report - 1987. Reclamation Research Technical Advisory Committee. 67 pp. No longer available.**

This annual report describes the expenditure of $500,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

48. **RRTAC 88-7: Baseline Growth Performance Levels and Assessment Procedure for Commercial Tree Species in Alberta's Mountains and Foothills. W.R. Dempster and Associates Ltd. 66 pp. $5.00**

Data on juvenile height development of lodgepole pine and white spruce from cut-over or burned sites in the Eastern Slopes of Alberta were used to define reasonable expectations of early growth performance as a basis for evaluating the success of reforestation following coal mining. Equations were developed predicting total seedling height and current annual height increment as a function of age and elevation. Procedures are described for applying the equations, with further adjustments for drainage class and aspect, to develop local growth performance against these expectations. The study was co-funded with The Coal Association of Canada.

49. **RRTAC 88-8: Alberta Forest Service Watershed Management Field and Laboratory Methods. A.M.K. Nip and R.A. Hursey. 4 Sections, various pagings. $10.00**

Disturbances such as coal mines in the Eastern Slopes of Alberta have the potential for affecting watershed quality during and following mining. The collection of hydrometric, water quality and hydrometeorologic information is a complex task. A variety of instruments and measurement methods are required to produce a record of hydrologic inputs and outputs for a watershed basin. There is a growing awareness and recognition that standardization of data acquisition methods is required to ensure data comparability, and to allow comparison of data analyses. The purpose of this manual is to assist those involved in the field of data acquisition by outlining methods, practices and instruments which are reliable and recognized by the International Organization for Standardization.

50. **RRTAC 88-9: Computer Analysis of the Factors Influencing Groundwater Flow and Mass Transport in a System Disturbed by Strip Mining. F.W. Schwartz and A.S. Crowe. 78 pp. $10.00**

Work presented in this report demonstrates how a groundwater flow model can be used to study a variety of mining-related problems such as declining water levels in areas around the mine as a result of dewatering, and the development of high water tables in spoil once resaturation is complete. This report investigates the role of various hydrogeological parameters that influence the magnitude, timing, and extent of water level changes during and following mining at the regional scale. The modelling approach described here represents a major advance on existing work.

51. **RRTAC 88-10: Review of Literature Related to Clay Liners for Sump Disposal of Drilling Wastes. D.R. Pauls, S.R. Moran and T. Macyk. 61 pp. $5.00**

The report reviews and analyses the effectiveness of geological containment of drilling waste in sumps. Of particular importance was the determination of changes in properties of clay materials as a result of contact with highly saline brines containing various organic chemicals.

52. **RRTAC 88-11: Highvale Soil Reconstruction Project: Five Year Summary. D.N. Graveland, T.A. Oddie, A.E. Osborne and L.A. Panek. 104 pp. $10.00**

This report provides details of a five year study to determine a suitable thickness of subsoil to replace over minespoil in the Highvale plains coal mine area to ensure return of agricultural capability. The study also examined the effect of slope and aspect on agricultural capability. This study was funded and managed with industry assistance.

53. **RRTAC 88-12: A Review of the International Literature on Mine Spoil Subsidence. J.D. Scott, G. Zinter, D.R. Pauls and M.B. Dusseault. 36 pp. $10.00**

The report reviews available engineering literature relative to subsidence of reclaimed mine spoil. The report covers methods for site investigation, field monitoring programs and lab programs, mechanisms of settlement, and remedial measures.

54. **RRTAC 89-1: Reclamation Research Annual Report - 1988. 74 pp. $5.00**

This annual report describes the expenditure of $280,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

55. **RRTAC 89-2: Proceedings of the Conference: Reclamation, A Global Perspective. D.G. Walker, C.B. Powter and M.W. Pole (Compilers). 2 Vols., 854 pp. $10.00**

Over 250 delegates from all over the world attended this conference held in Calgary in August, 1989. The proceedings contains over 85 peer-reviewed papers under the following headings: A Global Perspective; Northern and High Altitude Reclamation; Fish & Wildlife and Rangeland Reclamation; Water; Herbaceous Revegetation; Woody Plant Revegetation and Succession; Industrial and Urban Sites; Problems and Solutions; Sodic and Saline Materials; Soils and Overburden; Acid Generating Materials; and, Mine Tailings.

56. **RRTAC 89-3: Efficiency of Activated Charcoal for Inactivation of Bromacil and Tebuthiuron Residues in Soil. M.P. Sharma. 38 pp. $5.00**

Bromacil and Tebuthiuron were commonly used soil sterilants on well sites, battery sites and other industrial sites in Alberta where total vegetation control was desired. Activated charcoal was found to be effective in binding the sterilants in greenhouse trials. The influence of factors such as herbicide:charcoal concentration ratio, soil texture, organic matter content, soil moisture, and the time interval between charcoal incorporation and plant establishment were evaluated in the greenhouse.

57. **RRTAC 89-4: Manual of Plant Species Suitability for Reclamation in Alberta - 2nd Edition. Hardy BBT Limited. 436 pp. $10.00**

This is an updated version of RRTAC Report 80-5 which describes the characteristics of 43 grass, 14 forb and 34 shrub and tree species which make them suitable for reclamation in Alberta. The report has been updated in several important ways: a line drawing of each species has been added; the range maps for each species have been redrawn based on an ecosystem classification of the province; new information (to 1990) has been added, particularly in the sections on reclamation use; and the material has been reorganized to facilitate information retrieval. Of greatest interest is the performance chart that precedes each species and the combined performance charts for the grass, forb, and shrub/tree groups. These allow the reader to pick out at a glance species that may suit their particular needs. The report was produced with the assistance of a grant from the Recreation, Parks and Wildlife Foundation.

58. **RRTAC 89-5: Battle River Soil Reconstruction Project Five Year Summary. L.A. Leskiw. 188 pp. $10.00**

This report summarizes the results of a five year study to investigate methods required to return capability to land surface mined for coal in the Battle River area of central Alberta. Studies were conducted on: the amounts of subsoil required, the potential of gypsum and bottom ash to amend adverse soil properties, and the effects of slope angle and aspect. Forage and cereal crop growth was evaluated, as were changes in soil chemistry, density and moisture holding characteristics.

59. **RRTAC 89-6: Detailed Sampling, Characterization and Greenhouse Pot Trials Relative to Drilling Wastes in Alberta. T.M. Macyk, F.I. Nikiforuk, S.A. Abboud and Z.W. Widtman. 228 pp. $10.00**

This report summarizes a three-year study of the chemistry of freshwater gel, KCl, NaCl, DAP, and invert drilling wastes, both solids and liquids, from three regions in Alberta: Cold Lake, Eastern Slopes, and Peace River/Grande Prairie. A greenhouse study also examined the effects of adding various amounts of waste to soil on grass growth and soil chemistry. Methods for sampling drilling wastes are recommended.

60. **RRTAC 89-7: A User's Guide for the Prediction of Post-Mining Groundwater Chemistry from Overburden Characteristics. M.R. Trudell and D.C. Cheel. 55 pp. $5.00**

This report provides the detailed procedure and methodology that is required to produce a prediction of post-mining groundwater chemistry for plains coal mines, based on the soluble salt characteristics of overburden materials. The fundamental component of the prediction procedure is the geochemical model PHREEQE, developed by the U.S. Geological Survey, which is in the public domain and has been adapted for use on personal computers.

61. **RRTAC 90-1: Reclamation Research Annual Report - 1989. 62 pp. $5.00**

This annual report describes the expenditure of $480,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

62. **RRTAC 90-2: Initial Selection for Salt Tolerance in Rocky Mountain Accessions of Slender Wheatgrass and Alpine Bluegrass. R. Hermesh, J. Woosaree, B.A. Darroch, S.N. Acharya and A. Smreciu. 40 pp. $5.00**

Selected lines of slender wheatgrass and alpine bluegrass collected from alpine and subalpine regions of Alberta as part of another native grass project were evaluated for their ability to emerge in a saline medium. Eleven slender wheatgrass and 72 alpine bluegrass lines had a higher percentage emergence than the Orbit Tall Wheatgrass control (a commonly available commercial grass). This means that as well as an ability to grow in high elevation areas, these lines may also be suitable for use in areas where saline soil conditions are present. Thus, their usefulness for reclamation has expanded.

63. **RRTAC 90-3: Natural Plant Invasion into Reclaimed Oil Sands Mine Sites. Hardy BBT Limited. 65 pp. $5.00**

Vegetation data from reclaimed sites on the Syncrude and Suncor oil sands mines have been summarized and related to site and factors and reclamation methods. Natural invasion into sites seeded to agronomic grasses and legumes was minimal even after 15 years. Invasion was slightly greater in sites seeded to native species, but was greatest on sites that were not seeded. Invasion was mostly from agronomic species and native forbs; native shrub and tree invasion was minimal.

64. **RRTAC 90-4: Physical and Hydrological Characteristics of Ponds in Reclaimed Upland Landscape Settings and their Impact on Agricultural Capability. Moran, S.R., T.M. Macyk, M.R. Trudell and M.E. Pigot, Alberta Research Council. 76 pp. $5.00**

The report details the results and conclusions from studying a pond in a reclaimed upland site in Vesta Mine. The pond formed as a result of two factors: (1) a berm which channelled meltwater into a series of subsidence depressions, forming a closed basin; and (2) low hydraulic conductivity in the lower subsoil and upper spoil as a result of compaction during placement and grading which did not allow for rapid drainage of ponded water. Ponds such as this in the reclaimed landscape can affect agricultural capability by: (1) reducing the amount of farmable land (however, the area covered by these ponds in this region is less than half of that found in unmined areas); and, (2) creating the conditions necessary for the progressive development of saline and potentially sodic soils in the area adjacent to the pond.

65. **RRTAC 90-5: Review of the Effects of Storage on Topsoil Quality. Thurber Consultants Ltd., Land Resources Network Ltd., and Norwest Soil Research Ltd. 116 pp. $10.00**

The international literature was reviewed to determine the potential effects of storage on topsoil quality. Conclusions from the review indicated that storage does not appear to have any severe and longterm effects on topsoil quality. Chemical changes may be rectified with the use of fertilizers or manure. Physical changes appear to be potentially less serious than changes in soil quality associated with the stripping and respreading operations. Soil biotic populations appear to revert to pre-disturbance levels of activity within acceptable timeframes. Broad, shallow storage piles that are seeded to acceptable grass and legume species are recommended; agrochemical use should be carefully controlled to ensure soil biota are not destroyed.

66. **RRTAC 90-6: Proceedings of the Industry/Government Three-Lift Soils Handling Workshop. Deloitte & Touche. 168 pp. $10.00**

This report documents the results of a two-day workshop on the issue of three-lift soils handling for pipelines. The workshop was organized and funded by RRTAC, the Canadian Petroleum Association and the Independent Petroleum Association of Canada. Day one focused on presentation of government and industry views on the criteria for three-lift, the rationale and field data in support of three- and two-lift procedures, and an examination of the various soil handling methods in use. During day two, five working groups discussed four issues: alternatives to three-lift; interim criteria and suggested revisions; research needs; definitions of terms. The results of the workshop are being used by a government/industry committee to revise soils handling criteria for pipelines.